Hardwood Thinning and Spacing

Moderator:

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THINNING TO IMPROVE GROWTH AND CONTROL THE CANKER DECAY FUNGUS *INONOTUS HISPIDUS* IN A RED OAK-SWEETGUM STAND IN THE MISSISSIPPI DELTA

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Abstract–Thinning was applied to a 55-year-old, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand in the Delta region of western Mississippi in late summer 1997. The thinning operation was a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus*, a canker decay fungus that causes serious degrade and cull, especially in willow oak (*Quercus phellos* L.) and water oak (*Q. nigra* L.). Prior to thinning, stand density averaged 98 trees and 125 square feet of basal area per acre. Quadratic mean diameter was 15.4 inches, while stocking averaged 102 percent across the study area. Thinning reduced stand density to 32 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 18.4 inches, and reduced stocking to 47 percent. Thinning also increased the red oak component of the stand from 47 percent of the basal area prior to thinning to 59 percent of the basal area after thinning. There has been little stand-level growth during the first 3 years following the thinning operation. Thinning significantly increased diameter growth of residual trees, especially red oaks, but has not yet produced a significant increase in quadratic mean diameter. Even trees in the dominant crown class experienced increased diameter growth as a result of the thinning operation. Epicormic branching varied widely between species groups. Thinning had no significant effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. Three years after thinning, epicormic branches were most numerous on low-vigor sweetgum trees in the lower crown classes. Most importantly, thinning had no effect on the production of epicormic branches along the boles of red oak crop trees.

INTRODUCTION

A combination of thinning and improvement cutting is often used in mixed-species, southern bottomland hardwood forests to not only enhance both stand-level and tree-level growth, but also to improve both species composition and quality of the stand (Meadows 1996). These three characteristics – growth rate, species composition, and quality – are critically important for the profitable management of hardwood stands for high-quality sawtimber production.

Thinning regulates stand density and increases diameter growth of residual trees. In general, diameter growth response increases as the intensity of the thinning increases. However, very heavy thinning may reduce stand density to such a low level that stand-level growth is greatly curtailed even though tree-level growth is greatly enhanced. Stocking simply becomes so low that the stand does not fully realize the potential productivity of the site. Recommended minimum stocking levels necessary to maintain satisfactory stand-level growth have been reported to be 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in Allegheny hardwood stands (Lamson and Smith 1988). Thinning in a young water oak plantation to a residual stocking level of 33 percent created a severely understocked condition that will depress stand-level growth for many years (Meadows and Goelz 2001).

Thinning sometimes has adverse effects on the bole quality of residual trees. The production of epicormic branches along the boles of residual trees is often associated with poorly designed thinning operations. However, in stands thinned from below, the proportion of dominant and codominant trees in the residual stand increases as the intensity of the thinning increases. These vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less-vigorous, lower-crown-class trees (Meadows 1995). Consequently, the production of epicormic branches along the boles of residual trees may actually decrease after well-designed thinnings (Sonderman and Rast 1988).

This combination of thinning and improvement cutting typically used in mixed-species hardwood stands is also designed to improve both species composition and quality of the residual stand (Meadows 1996). In general, the objective is to decrease the proportion of low-value trees and thus to increase the proportion of high-value trees. The emphasis for this component of the cutting operation is on the value, or quality, of the individual trees. Trees that are damaged, diseased, of poor bole quality, or of an undesirable species are removed from the stand, whereas healthy, high-quality trees of desirable species are retained. Improvement cuttings are often performed in stands that contain a high

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proportion of diseased trees in an effort to eliminate disease-causing fungi from the stand.

Hardwood stands in the Delta region of Mississippi are often infested with *Inonotus hispidus*, a canker decay fungus that causes the disease commonly known as hispidus canker. The fungus is found most frequently on willow oak and water oak, but also occurs on Nuttall oak (*Quercus nuttallii* Palmer), white oak (*Q. alba* L.), and hickory (*Carya* spp.). Hispidus canker causes serious degrade and cull in infested trees. Damage occurs primarily in the form of heartwood decay, in which the wood behind the canker becomes soft and delignified. The fungus results in the formation of a large, spindle-shaped canker usually at the site of an old branch stub 12 to 15 feet or more up the bole of the infected tree (McCracken 1978). The central part of the canker is sunken and covered with bark. In addition to the degrade caused by the heart rot, presence of the hispidus canker greatly increases the possibility of stem breakage at the site of the canker itself. Improvement cuttings to remove trees with hispidus canker have been successful in reducing spore production and dissemination within the stand, thus minimizing the possibility of the spread of the disease to adjacent trees (McCracken and Toole 1974).

The study reported here is part of a much larger research project that is investigating the relationships between silvicultural practices and insect and disease populations in southern hardwood forests. Specifically, the goals of this larger project are: (1) to better understand and to quantify the effects of stand modification on insect and disease populations in southern hardwood forests, and (2) to use this knowledge to develop pest management recommendations with respect to silvicultural practices in southern hardwood forests.

This paper reports only the silvicultural component of the overall project on one of our study sites. The specific objectives of this individual study are: (1) to determine the effects of thinning on stand growth, development, and yield, and (2) to determine the effects of thinning on individual-tree growth and bole quality. A third objective, not covered in this paper, is to determine the effects of thinning on insect and disease populations, with special emphasis on those pests that lead to degrade and/or mortality.

METHODS

Study Area

The study is located on the Delta National Forest in the Delta region of western Mississippi. The study site is adjacent to Ten Mile Bayou, within the floodplain of the Big Sunflower River, in southeastern Sharkey County. The site is nearly flat and is subject to frequent periodic flooding during the winter and spring months. Floodwaters may remain on the site for several weeks during this period.

Soils across most of the study site belong to the Sharkey series, but smaller areas of Alligator soils are interspersed with the Sharkey soils. Dowling soils also occur in small depressions. All three soils are poorly drained clays that shrink and form wide cracks when dry and expand when wet. These soils formed in fine-textured Mississippi River sediments deposited in slackwater areas of the floodplain. Broadfoot (1976) reported average site indexes of the Sharkey soils to be 92 feet at 50 years for willow oak and 91 feet at 50 years for Nuttall oak. Average site index of the Alligator soils was 88 feet at 50 years for both species. Broadfoot (1976) did not supply similar information for the Dowling soils.

The study area is contained within a 55-year-old red oak-sweetgum stand. Principal red oak species are willow and Nuttall oaks. In addition to sweetgum, other common species include sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), common persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and honeylocust (*Gleditsia triacanthos* L.).

Plot Design

Plot design was modified from the format for standard plots for silvicultural research, as originally recommended by Marquis and others (1990). Each treatment was uniformly applied across a 4.8-acre rectangular treatment plot that measured 6 by 8 chains (396 by 528 feet). Four, 0.6-acre rectangular measurement plots were established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet). A 1-chain buffer strip was established around the four measurement plots. The entire study covered an area of 9.6 acres.

Treatments

Only two treatments were applied to the study area: (1) an unthinned control, and (2) heavy thinning. The thinning operation was a combination of low thinning and improvement cutting. Personnel from the Delta National Forest marked the stand to remove most of the pulpwood-sized trees as well as those sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus*.

Four replications of the two treatments were applied in a randomized complete block design to the eight plots (experimental units) in August 1997. Trees were directionally felled by a mechanized feller with a continuously running cutting head. Merchantable products in the form of longwood were removed with rubber-tired skidders.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. We recorded species, diameter at breast height (dbh), crown class, and tree class as defined by Meadows (1996) on all trees greater than or equal to 5.5 inches dbh. The number of epicormic branches on the 16-foot butt log was also recorded on those trees designated as “leave” trees. Log grade, as defined by Rast and others (1973), of the 16-foot butt log and sawtimber merchantable height were recorded on those “leave” trees greater than or equal to 13.5 inches dbh. Crown class, dbh, and the number of epicormic branches on the 16-foot butt log were measured annually for the first 3 years after thinning.

Table 1—Stand conditions and individual-tree diameter growth 3 years after application of two thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Mortality	Basal area	Basal area growth	Stocking	Quadratic mean Diameter	Cumulative diameter growth
	(No./acre)	(Pct)	(Sq ft/acre)	(Sq ft/acre)	(Pct)	(In.)	(In.)
Unthinned	99 a	1.0 a	133 a	4 a	108 a	15.7 a	0.23 b
Thinned	30 b	6.2 a	60 b	1 a	48 b	19.0 a	0.60 a

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the study area averaged 98 trees and 125 square feet of basal area per acre, with a quadratic mean diameter of 15.4 inches. The average stocking of 102 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). We found no significant differences among the plots in any of these preharvest characteristics. The stand was fairly dense, but many of the dominant and codominant trees were healthy and exhibited few symptoms of poor vigor. Unfortunately, hispidus canker was observed on approximately 24 percent of the red oaks in the study area.

The stand was clearly dominated by red oak and sweetgum. Red oaks (primarily willow and Nuttall oaks) accounted for about 47 percent of the basal area of the preharvest stand. Red oaks dominated the upper canopy of the stand and had a quadratic mean diameter of 17.2 inches. Sweetgum accounted for about 46 percent of the basal area and occurred in both the upper and middle canopies. Sweetgum quadratic mean diameter was 14.6 inches. Other species, principally sugarberry and American elm, made up the remaining 7 percent of the basal area. These trees were found almost exclusively in the lower canopy of the stand.

Stand Development Following Thinning

Thinning reduced stand density to 32 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 18.4 inches, and reduced stocking to 47 percent. It removed 67 percent of the trees and 53 percent of the basal area. Average volumes removed during the thinning operation were 3,500 board feet per acre (Doyle scale) of sawtimber and 11 cords per acre of pulpwood. Average dbh of trees removed was 13.5 inches. Thinning produced stand characteristics significantly different from the unthinned control.

This heavy thinning reduced stand density to a level approaching the minimum residual stocking level necessary to maintain satisfactory stand-level growth, as recommended for other hardwood forest types (Hilt 1979, Lamson and Smith 1988). The heavier-than-normal thinning was necessary in this stand because of the desire to remove all of the red oaks infected with hispidus canker. However, even with these additional removals of diseased red oaks, thinning improved species composition of the stand. Thinning increased the red oak component of the stand to 59 percent of the basal area and reduced the sweetgum component to 37 percent of the residual basal area.

During the 3 years following thinning, stand-level growth has been negligible in both the unthinned control and the thinned plots (table 1). In fact, cumulative basal area growth and the increase in stocking percent during the 3-year period following thinning were actually lower in the thinned plots than in the unthinned control, although these differences were not statistically significant. Apparently, this heavy thinning created an understocked stand that will require many years to fully recover from the drastic reduction in stand density.

Diameter Growth

We found significant differences between the thinning treatment and the unthinned control in cumulative diameter growth of individual trees 3 years after treatment (table 1). Thinning increased diameter growth of residual trees by 161 percent when compared to the unthinned control.

Red oaks and sweetgums were similar in their diameter growth response to the thinning treatment (figure 1). Thinning more than doubled diameter growth of both species groups. Cumulative diameter growth of residual red oaks in the thinned plots was 0.64 inches, whereas residual sweetgums in the thinned plots averaged 0.56 inches of

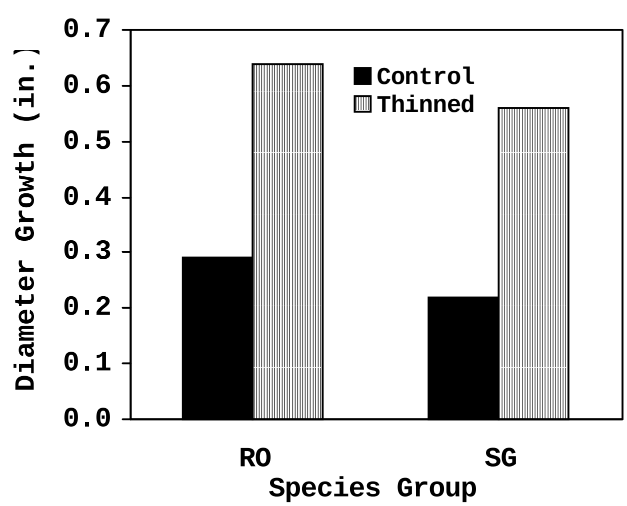

Figure 1–Diameter growth of residual trees, by species group, during the first 3 years after application of two thinning treatments (RO = red oak, SG = sweetgum).

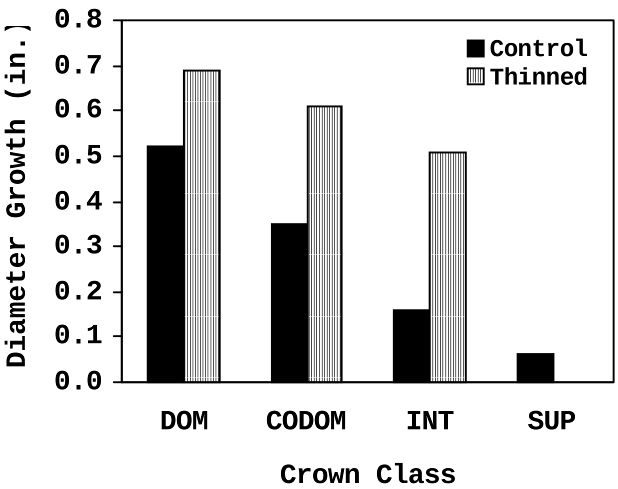

Figure 2–Diameter growth of residual trees, by crown class, during the first 3 years after application of two thinning treatments (DOM = dominant, CODOM = codominant, INT = intermediate, SUP = suppressed).

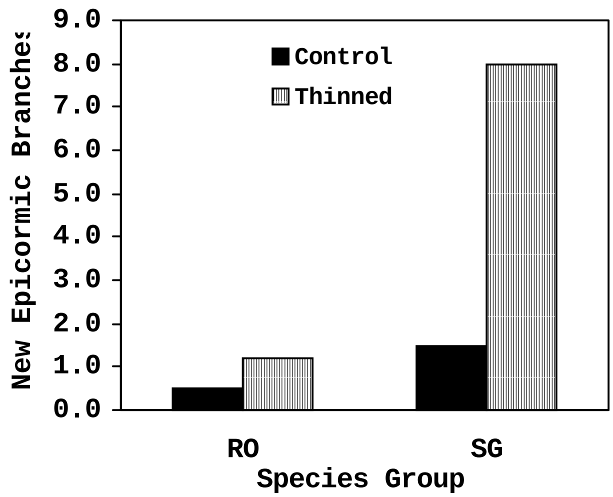

Figure 3–Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 3 years after application of two thinning treatments (RO = red oak, SG = sweetgum).

diameter growth over the 3-year period. Cumulative diameter growth of both red oaks and sweetgums in the unthinned control averaged less than 0.30 inches.

Of particular significance in this study is the observation that thinning increased diameter growth of both dominant and codominant trees, when averaged across all species (figure 2). Thinning increased diameter growth of dominant trees by about 33 percent and increased diameter growth of codominant trees by about 74 percent over the unthinned control. Thinning also more than tripled cumulative diameter growth of trees in the intermediate crown class. No comparisons could be made for trees in the suppressed crown class because thinning removed all of the suppressed trees.

It is clear that thinning successfully increased cumulative diameter growth of residual trees 3 years after treatment. Excellent diameter growth responses were observed for both red oak and sweetgum trees in the dominant and codominant crown classes. These trees, especially the red oaks, were classified as crop trees and were considered to be the most desirable trees in the stand for high-quality sawtimber production. The thinning operation, at least through the first 3 years, has been very successful in greatly enhancing the diameter growth of the most valuable trees in the stand.

Epicormic Branching

The production of epicormic branches along the merchantable boles of residual trees can be a serious problem in thinning hardwood stands. These epicormic branches cause defects in the underlying wood and can reduce both log grade and subsequent lumber value. However, well-designed thinnings and proper marking rules can minimize the production of new epicormic branches in most hardwood stands.

In this study, thinning had no significant effects on either the total number or the number of new epicormic branches found on the butt logs of residual trees 3 years after thinning. Residual trees in the thinned plots averaged a total of 6.5 epicormic branches on the butt log; included in this total were 4.1 new epicormic branches produced on the butt log during the 3 years following thinning. On the other hand, trees in the unthinned control averaged 3.8 epicormic branches on the butt log; there were 1.0 new epicormic branches produced on the butt log of these trees during the same 3-year period. Even though residual trees in the thinned plots averaged more total epicormic branches and more new branches on the butt log than trees in the unthinned control, these differences were not statistically significant. Production of new epicormic branches on the butt log varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many other healthy trees produced only a few. Low-vigor trees, however, generally produced many new epicormic branches.

We found wide variation between the red oaks and sweetgum in the number of new epicormic branches produced on the butt log during the 3 years following thinning (figure 3). Thinning had very little effect on the production of new epicormic branches in red oak, but caused a very large increase in the number of new epicormic branches on the butt logs of residual sweetgum trees 3 years after thinning. Most of the residual red oaks in the thinned stand were high-vigor dominant or codominant trees that are generally less likely to produce epicormic branches than are trees in poor health. Consequently, we found very few new epicormic branches on the butt logs of residual red oaks, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching. Our observations in this study strongly support the hypothesis proposed by Meadows (1995) that healthy, vigorous trees, even of highly susceptible species, are much less likely to produce epicormic branches than are trees in poor health.

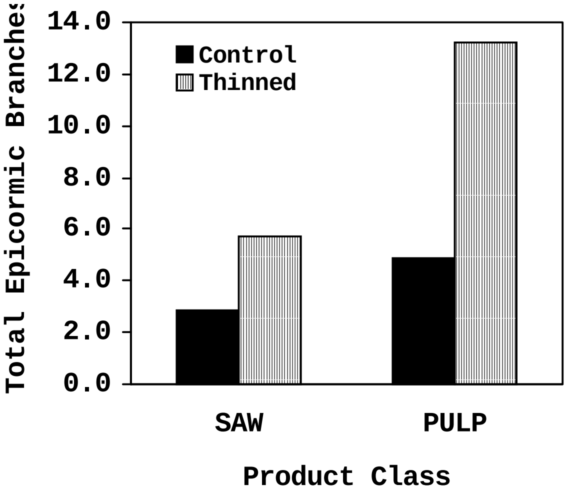

Figure 4–Total number of epicormic branches on the butt logs of residual trees, by product class, 3 years after application of two thinning treatments (SAW = sawtimber, PULP = pulpwood).

When evaluating the effects of thinning on epicormic branching, the most important consideration, however, is the total number of epicormic branches found on the butt logs of the crop trees. These trees are favored during the thinning operation and are most likely to produce high-quality sawtimber. Sawtimber trees in the thinned plots averaged 2.8 more epicormic branches on the butt log than sawtimber trees in the unthinned control, when averaged across all species (figure 4). However, this small difference was not statistically significant. On the other hand, pulpwood trees in the thinned plots had many more epicormic branches on the butt log than pulpwood trees in the unthinned control 3 years after thinning. Most of the pulpwood-sized trees in the residual stand after thinning were relatively low-vigor, lower-crown-class trees that produced many new epicormic branches following the thinning treatment.

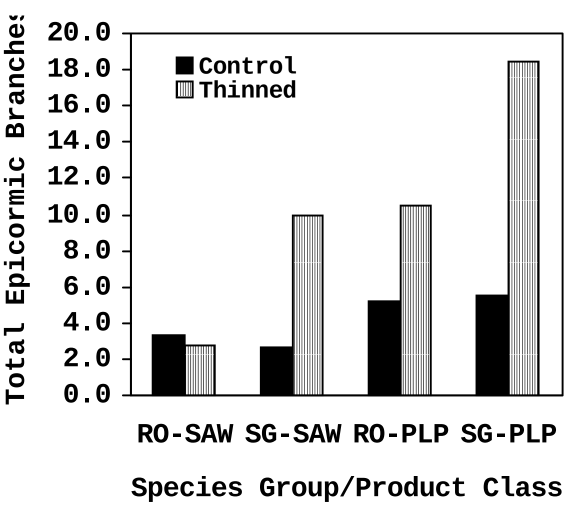

Figure 5–Total number of epicormic branches on the butt logs of residual trees, by species group and product class, 3 years after application of two thinning treatments (RO-SAW = red oak sawtimber, SG-SAW = sweetgum sawtimber, RO-PLP = red oak pulpwood, SG-PLP = sweetgum pulpwood).

Although sawtimber trees in the thinned plots had more epicormic branches on the butt log than sawtimber trees in the unthinned control (figure 4), most of this increase in the number of epicormic branches was found on sawtimber-sized sweetgum trees rather than on sawtimber-sized red oak trees (figure 5). In fact, sweetgum sawtimber trees in the thinned plots averaged 7.3 more epicormic branches on the butt log than sweetgum sawtimber trees in the unthinned control 3 years after treatment. In contrast, red oak sawtimber trees in the thinned plots actually had slightly fewer epicormic branches on the butt log than red oak sawtimber trees in the unthinned control, but this difference was not statistically significant. Consequently, we can conclude that, in this study, thinning to a low level of residual stocking had no effect on the total number of epicormic branches on the butt logs of red oak sawtimber trees, the most valuable trees in the stand.

CONCLUSIONS

1. The thinned stand has been very slow to recover from the thinning operation, with little stand-level growth during the first 3 years.

2. Thinning increased diameter growth of residual trees, especially red oaks, but has not yet resulted in an increase in quadratic mean diameter.

3. Thinning increased diameter growth of codominant trees by 74 percent and diameter growth of dominant trees by 33 percent.

4. Thinning had no effect on epicormic branching in red oak sawtimber trees, but greatly increased the production of new epicormic branches in sweetgum sawtimber trees.

5. Epicormic branches were most numerous on the butt logs of low-vigor, lower-crown-class trees; this was especially true for sweetgum.

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LITERATURE CITED

Broadfoot, Walter M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3):103-104.

Hilt, Donald E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Lamson, Neil I.; Smith, H. Clay. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Marquis, Dave; Smith, Clay; Lamson, Neil [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. [Warren, PA]: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

McCracken, F.I. 1978. Canker-rots in southern hardwoods. Forest Insect & Disease Leaflet 33. Washington, DC: U.S. Department of Agriculture, Forest Service. 4 p.

McCracken, F.I.; Toole, E.R. 1974. Felling infected oaks in natural stands reduces dissemination of *Polyporus hispidus* spores. Phytopathology. 64(2):265-266.

Meadows, James S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, Glenn; Meyer, Dan, eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the twenty-third annual hardwood symposium; 1995 May 17-20; Cashiers, NC. [Memphis, TN]: National Hardwood Lumber Association: 19-25.

Meadows, James S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Clemson, SC: Consortium for Research on Southern Forested Wetlands, Clemson University: 98-101.

Meadows, James S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1):31-39.

Rast, Everette D.; Sonderman, David L.; Gammon, Glenn L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

Sonderman, David L.; Rast, Everette D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

GROWTH OF A 30-YEAR CHERRYBARK OAK PLANTATION 6 YEARS AFTER THINNING

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Abstract—A 24-year cherrybark oak (*Quercus falcata* var. *pagodifolia*) plantation in the Coastal Plain of west Tennessee was thinned during the winter of 1994-1995. Growth in the plantation was severely stagnated. Trees were planted at a 9 by 9-foot spacing and survival was 69 percent after 24 years after decreasing from 88 percent at age 15. The plantation should have been thinned earlier to avoid the onset of stagnation and the resulting decline in rate of diameter and volume growth. Approximately 50 percent of the stems and 35 percent of the basal area were cut during the row thinning, taking every second row. Results six growing seasons after thinning indicate that the remaining residual trees are increasing in diameter at an annual rate greater than the 9 years prior to the thinning. The plantation volume cut during the thinning operation was replaced by growth on the remaining trees within six years. The volume is accumulating on a fewer number of trees yielding larger diameter trees and increased value over a shorter period of time. A second thinning is projected by age 35. These trends can be used by practitioners as preliminary information on the growth and development of a 30-year-old cherrybark oak plantation before and after thinning.

INTRODUCTION

Thinning is the one operation where merchantable value can be easily increased through regulating stand density and augmenting the diameter growth of residual trees (Hopper and others 1995). Its primary purpose is to salvage trees in immature stands that would normally be lost due to natural stand mortality. Thinning affects merchantable yield by distributing volume growth on fewer, larger trees (Smith 1962).

Although there is a wealth of information about thinning in southern pine stands (Moehring and others 1980), there is a conspicuous absence of thinning information in natural hardwood stands and even less in planted hardwood stands. Meadows and Goelz (2001) recently reviewed the literature on thinning in natural hardwood stands and planted stands.

This research capitalizes on a study for genetic improvement of cherrybark oak. The plantation has been closely monitored and measured periodically for 30 years. This article presents the growth and development of the plantation for the first 24 years before thinning, then the growth results 6 years after thinning. Although this is an unreplicated case study, the 30-year data will give practitioners some long-term information on growth and development of cherrybark oak in plantations before and after thinning.

STUDY AREA

The 1.8-acre cherrybark oak plantation is located on Natchez Trace State Forest (NTSF) in Henderson County, TN, located approximately 10 miles northeast of Lexington, TN near the confluence of Scarce Creek and the Big Sandy River. The forest is managed by the Tennessee Department of Agriculture, Forestry Division (TDA-FD). The plantation is in a second bottom with moderately well-drained, Udifluvent soils (Collins and Iuka series) formed in young alluvium washed from loessal and sandy Coastal Plain materials (Smalley 1991). The area is occasionally flooded during the late winter and early spring by streams or by runoff from higher lying areas, however the duration is only for a few days. Using Smalley's (1991) landscape classification, the study site is landtype #23: narrow moist bottoms. Annual precipitation averages 51 inches, with July through September as the driest months and late winter to early spring as the wettest. Average site index (base age 50) is estimated to be 100-110 feet for cherrybark oak. (Clatterbuck 1987, Smalley 1991).

The NTSF was part of the federal Resettlement Administration purchase of land during the mid-1930's. Before the purchase, the area consisted of marginal and submarginal farms. Most of the cleared land had sustained severe sheet and gully erosion. After the federal government bought the property, many families leased their homes and land and some remained for more than 20 years. By 1959, all families had relocated; their homes and outbuildings were sold, moved or demolished.

The study area is adjacent to Dry Branch, a tributary of Scarce Creek, was cultivated through the mid-1950's and then abandoned. Sediment was deposited from the uplands on this second bottom area until the active erosion was controlled. A variety of soil textures occur because of mixing during transport, active erosion and differential rates of deposition. The field was then maintained in pasture or hay until planting.

The field was planted with 1-0 cherrybark oak in January of 1969 at 9 by 9-foot spacing as part of a tree improvement

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study initiated by the USDA Forest Service, Southern Research Station and TDA-FD to develop a source of genetically improved cherrybark oak for planting in west Tennessee. The planting design was a randomized complete block with 4-tree family plots, 18 families from a Warren County, MS seed source, and 10 replications with 72 trees per replicate.

The planting site was an old field that was heavy in Johnson grass, tall fescue and vetch. Disking was used to prepare the site for planting. Disking and mowing after planting was done at least twice a year for the first four years. Height measurements were taken at age 4 (1973) and age 7 (1976); height and diameter measurements at age 10 (1979), age 15 (1984), and age 24 (1993). The plantation was thinned during the spring of 1994 and the remeasurement was at age 30 (1999).

METHODS

The plantation was measured at age 24 (1993) before thinning. Basal area in 1993 was 103 square feet per acre. Superior phenotypes based on height, diameter and volume were identified. A thinning regime was formulated with the retention of these phenotypes to continue the genetic objectives of the study, namely creation of a cherrybark oak seed production area. The thinning can best be described as a row thinning where every second row was harvested. Selected phenotypes within the harvested rows were retained and one tree on each side of retained phenotypic trees within leave rows was cut. No attempt was made to select inferior trees during the thinning. The goal was to thin approximately 50 percent of the trees resulting in a reduction of 40 percent of the basal area.

RESULTS

Plantation Development after Planting and before Thinning

Very little height growth occurred during the first four growing seasons (table 1), but the rate of height growth increased until the 15-year measurement, then the rate decreased afterward (table 2). Slow initial height growth is characteristic of oak (McGee and Loftis 1986), and may have been further retarded by severe grass and herbaceous competition. The site received at least two mowings per year for the first four growing seasons, which permitted considerable competition from herbaceous vegetation. Grass is perhaps the greatest competitor of planted seedlings (Ford 1999). However, survival rates indicate that cherrybark oak can tolerate such competition in the seedling stage and eventually overtop it, although the growth rate during this period is small. Once established, growth rate increases considerably (table 2) and continues to the 15-year measurement.

Survival was between 88 and 93 percent through age 15, then dropped to 69 percent at age 24. The decrease in survival suggests that trees were exceeding the amount of growing space. The presence of many dead trees scattered throughout the plantation and the presence of epicormic branches along the boles of many trees indicated that the plantation was approaching stagnation. Diameter growth rate was decreasing (tables 1 and 2), another indication that stagnation was taking place. Field observations indicate that adjacent crowns were overlapping and the crowns of many of the subordinate, less vigorous trees were spindly, dying back or dead. From age 15 through age 24 the number of trees per acre decreased from 473 to 372, a mortality rate of 21 percent. Clearly, the plantation should have been thinned at an earlier age to maintain or increase tree growth and development.

Plantation Development after Thinning

Prior to thinning (age 24), the plantation averaged 372 trees per acre (69 percent survival), average basal area of 103 square feet per acre with an average total height of 63 feet and a mean diameter of 6.9 inches. Total stand volume was 2,243 square feet per acre. These data are from all trees regardless of crown class.

Approximately 35 percent of the basal area, 50 percent of the stems and 45 percent of the volume were cut per acre during the thinning. Leaving some of the best phenotypes in the cut rows resulted in more basal area and volume being left than anticipated.

Six years after the thinning, total height continues to increase but at a decreasing rate (table 2). The rate of

Table 1—Changes at different ages, before and after thinning, in mean height, diameter, and volume of trees in a cherrybark oak plantation with associated changes in survival, basal areas and total volume for the plantation

	Individual Tree			Plantation			
Age (yrs)	Mean Height (ft)	Mean Diameter (in)	Mean Volume (cubic ft)	Survival (pct.)	Trees/Acre (#)	Basal Area (sq ft/ac)	Total Volume (cubic ft/ac)
4	2.3	—-	—	93	500	—-	—-
7	9.9	—-	—-	92	495	—-	—-
10	19.3	2.6	—-	91	490	18.1	—-
15	37.3	4.5	1.76	88	473	52.2	832.5
24	61.4	6.9	6.03	69	372	102.6	2,243.2
thinned at age 24							
30	75.6	8.8	12.21	-	190	81	2,139.9

Table 2—Average annual height, diameter and volume growth rates in a 30-year-old cherrybark oak plantation in west Tennessee

Age Interval (yrs)	Height growth rate (ft)	Diameter Growth Rate (in)	Volume Growth Rate (cubic ft)
0 – 4	0.6	—-	—-
5 – 7	2.5	—-	—-
8 – 10	3.1	—-	—-
11 – 15	3.6	0.38	—-
16 – 24	2.7	0.26	0.47
thinned at age 24			
25 – 30	2.4	0.31	1.03

annual diameter growth has increased to 3.1 inches per decade from 2.6 inches before thinning. Diameter growth rates were declining from ages 16-24 because of the onset of stagnation and then began to increase from ages 25-30 after thinning when more growing space was available for crown expansion (table 2).

Since thinning, basal area has increased from 65 to 81 square feet per acre in 6 years or 2.6 square feet per acre annually. If these rates of basal area growth continue, we expect another thinning will be necessary in four to six years.

Average volume per tree doubled in the six years following thinning from an average of 6 to 12 cubic feet per tree, an average annual growth per tree of 1.0 cubic feet per year. Even though approximately 50 percent (1,082 cubic feet per acre) of total volume was harvested during the thinning, total volume of the plantation increased from 1,161 to 2,320 cubic feet per acre or an average volume growth rate of 193 cubic feet per acre per year the following six years. The total amount of volume six years after thinning was essentially the same as the amount of volume before the cut (table 1). The volume is accumulating on a fewer number of trees yielding larger diameter trees and increased value over a shorter period of time.

Trees, particularly oaks, which have been repressed and are under stress have a tendency to develop epicormic branches (Clatterbuck 1993). Although the degree of epicormic branching was not quantitatively assessed in this study, we observed that the number of epicormic branches was greater in the intermediate and suppressed crown classes than the dominant and codominant classes before thinning. Meadows and Goelz (2001) reported similar findings with stressed water oak (*Q. nigra*) plantations. After thinning, epicormic branches remained and were more numerous on trees in subordinate crown classes. On the larger and more vigorous dominant and co-dominant cherrybark oak trees, there were fewer epicormic branches, some of these branches died and were shed and others remained becoming larger in diameter. Without base data for comparison, these trends are not quantifiable, but the thinned plantation does contain high-quality sawtimber trees with few if any epicormic branches.

The diameter distribution of the plantation before thinning resembled a bell-shaped curve with trees being the most abundant in the 8-inch diameter class (figure 1). Six years after thinning where nearly 50 percent of the trees were harvested, the diameter distribution begins to flatten and shift toward the larger diameter-size classes. The greatest number of trees were in the 8 and 10-inch diameter classes. This trend is usually found in even-aged stands of a single species as they develop and mature (Moehring and others 1980, Meadows and Goelz 2001).

DISCUSSION

The cherrybark oak plantation after 24 years was not growing in diameter at an acceptable rate. Diameter growth was 2.6 inches per decade, well below the 3.5 to 4.5 inches per decade that is considered good to excellent growth on productive bottomland sites (Putnam and others 1960). At age 24, the trees were declining because of the competition for growing space resulting in reduced tree growth, increased mortality and declining stand productivity. After thinning, more growing space was available allowing trees to increase in diameter and volume. Six years after thinning, total plantation volume was similar to that when the trees were cut. The volume increase is on fewer trees per acre with larger diameter size and volume per tree. At present rates of diameter and volume growth, the plantation is projected to need thinning again in four to six years.

The first thinning at age 24 probably occurred too late. Natural mortality in the nine years prior to thinning was 22 percent or about 101 trees per acre. The plantation should have been thinned much earlier to avoid growth declines, stress and mortality. The 9 by 9-foot plantation spacing appears desirable for developing merchantable boles and achieving diameters that can be harvested profitably (depending on markets) during the first thinning and achieving plantation basal area and volume growth. Closer

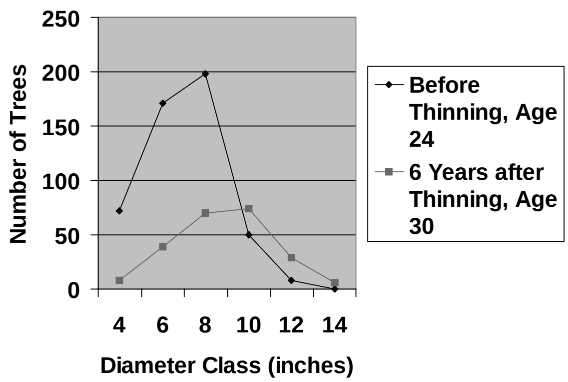

Figure 1—Diameter distribution before thinning and the diameter distribution six years after thinning in a 30-year-old cherrybark oak plantation

spacing will require thinning of smaller diameter material at an earlier age, while wider spacing delays the first thinning, but the tree diameters will be larger.

The tree improvement objective of creating a seed production area from the plantation favored row thinning. The advantage of row thinning is minimal damage to trees within the leave rows. The possible unfavorable effect of row thinning is the removal of good trees and leaving poor trees, creating broad variation between individuals. Many trees in the subordinate crown classes were left within the leave rows. These smaller trees probably deflated the average height, diameter and volume figures reported in this study. Low thinning would have taken most of the subordinate trees and provided a better choice for the leave trees to be retained. A few (eight trees) of the best phenotypic trees were left in the cut rows for future tree improvement studies. The next thinning will probably be a combination of low thinning to remove subordinate trees and a crown or high thinning to remove dominants and codominant trees that are influencing adjacent dominant and codominant trees.

The development of pure plantations generally does not allow the degree of vertical stratification found in mixed species stands. Trees of the same species of similar ages and regeneration origin usually grow and develop at similar rates. Dominance is not expressed quickly since the trees grow at similar rates. In contrast, stratification occurs usually at an early age in mixed species stands (Clatterbuck and Hodges 1988, Oliver 1978). Crown differentiation, especially between different species is readily apparent. The lack of early stratification in single species plantations obscures that these plantations are actively growing and increasing in size. The growth of these stands appears rather gradual. Practitioners should be aware that these pure stands could stagnate after just a few years of intense competition among neighboring trees.

ACKNOWLEDGMENTS

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REFERENCES

Clatterbuck, W.K. 1987. Height growth and site index curves for cherrybark oak and sweetgum in mixed, even-aged stands on the minor bottoms of central Mississippi. Southern Journal of Applied Forestry. 11(4): 219-222.

Clatterbuck, W.K. 1993. Are overtopped white oak good candidates for management? In: Brissette, J.C., ed. Proc. of the seventh biennial southern silvicultural conference: 1992 November 17-19; Mobile, Al. Gen. Tech. Rep.SO-93. New Orleans, LA: USDA, Forest Service, Southern Forest Experiment Station: 497-500.

Clatterbuck, W.K.; J. D. Hodges. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, U.S.A. Canadian Journal of Forest Research. 18(1): 12-18.

Ford, V. 1999. Competition control in plantation oak stands. In: Proceedings from Oak Regeneration Workshop; 1999 April 22; Knoxville, TN. The University of Tennessee, Dept. of Forestry, Wildlife & Fisheries, Knoxville: 27.

Hopper, G.M. (ed.); H. Applegate; D. Dale; R. Winslow. 1995. Forest practice guidelines for Tennessee. Agricultural Extension Service PB 1523, The University of Tennessee, Knoxville. 36 p.

McGee, C.E.; D.L. Loftis. 1986. Planted oaks perform poorly in North Carolina and Tennessee. Northern Journal of Applied Forestry. 3: 114-116.

Meadows, J.S.; J.C.G. Goelz. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1): 31-39.

Moehring, D.M.; J.D. Hodges; T.G. Matney. 1980. Biological assessment of thinning in southern pine plantations. Mississippi State University, Starkville. 171 p.

Oliver, C.D. 1978. The development of northern red oak in a mixed species forest in central New England. Yale University School For. Environ. Stud. Bull., 91. New Haven, CT. 63 p.

Putnam, J.A.; G.M. Furnival; J.S. McKnight. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. U.S. Department of Agriculture, Washington, DC. 102 p.

Smalley, G.W. 1991. Classification and evaluation of forest sites on the Natchez Trace State Forest, State Resort Park and Wildlife Management Area in west Tennessee. Gen. Tech. Rep. SO-85. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 73 p.

Smith, D.M. 1962. The Practice of Silviculture. Seventh Edition, New York: John Wiley & Sons, Inc. 578 p.

FERTILIZATION AND THINNING IN A 7-YEAR-OLD NATURAL HARDWOOD STAND IN EASTERN NORTH CAROLINA

Leslie P. Newton, Daniel J. Robison, Gerald Hansen, and H. Lee Allen[1]

Abstract—Young even-aged hardwood stands undergo a period of intense competition and self-thinning during the early years of stand development. During this time relatively little growth is accumulated by stems which will persist until rotation age. Silvicultural manipulations which accelerate the rate of stand development, concentrate growth on fewer stems of desirable species and reduce rotation age would be useful options for forest managers. This study reports on an experiment in a 7-year-old stand in northeastern NC, in which growth responses to thinning to 3000 trees per acre and fertilization with N and P were evaluated. Findings indicate that after 3 years, thinning alone did not significantly enhance growth, while fertilization alone or in combination with thinning enhanced growth, and in similar amounts.

INTRODUCTION

Accelerating the growth of naturally regenerated hardwood stands is an important goal of forest managers. Across the southern U.S. many of these stands are even-aged, having regenerated following clearcutting. Through the natural processes of regeneration (including stump and root sprouts, and seedlings), stand consolidation and self-thinning, timber typically reaches merchantable size in 40 to 60 years. Common methods of promoting the growth of these stands take place when the timber is at least pole-sized, often 20 to 30 years old, and stand density has naturally declined to a few thousand stems per acre. Fertilization and thinning in younger stands may accelerate the rate of stand development, concentrating growth on fewer and more valuable stems, and reducing rotation age. These changes could have significant economic advantages.

Studies in natural hardwoods have long demonstrated that thinning can have many positive benefits in production forestry, provided damage to the residual stand and soils are prevented (Gingrich 1971, Heitzman and Nyland 1991). Few studies have reported on stands less than 10 years old. Most reports are from Appalachian uplands. Fertilization in natural stands has been infrequently studied, with reports indicating a variety of stand responses (Dunn and others 1999, Graney and Rogerson 1985, Farmer and others 1970). It is well established that enhancing site resources through fertilization, and reducing inter-tree competition (and herbaceous competition) through density control, and these factors in combination, can enhance productivity, often for many years following treatment (Johnson and others 1997). In the current study we report initial findings from a fertilization and thinning trial in a young North Carolina coastal plain upland hardwood stand.

METHODS

The study site is located on International Paper Company land (formerly a Union Camp Corporation site) in northeastern North Carolina (Northampton County) on a coastal plain mineral flat of somewhat poorly to poorly drained silty clay loam (Lenoir series). These soils can be phosphorus-deficient, with relatively low productivity. The stand consists of naturally regenerated mixed pine-hardwoods, which grew following a commercial clearcut of the prior natural stand in 1990. The current dominant species are sweetgum (*Liquidambar styraciflua* L.), and red maple (*Acer rubrum* L.).

The experimental design was a 2 x 2 factorial (thinning and fertilization as main effects) with three blocks. Treatments were imposed when the stand was 7 years old with a density of approximately 8500 stems per acre. Treatment plots measure 166 ft. x 166 ft., with interior measurement plots of 100 ft. x 100 ft. Within each measurement plot there were 13 circular 154 sq. ft. subplots. Thinning was done in winter 1997 by reducing density to circa 3000 stems per acre with a brushcutter, using spacing and desirable species as a guide. Fertilizer was hand broadcast applied in spring 1998 as 200 lbs. per acre N (in urea and diammonium phosphate [DAP]) and 50 lbs. per acre P (in DAP).

Here we present data on mean tree size (Height and DBH) at age 10 (measured winter 2000/2001), and the 3 year increment between age 7 (measured May 1997) when treatments were applied and age 10. Stand volume, and increment, by treatment are also presented. Volume was estimated by summing subplot standing volumes for each treatment plot, and using an expansion factor to express them on a per acre basis. DBH and height were measured for all stems > 4.5 ft. tall and > 1.5 inches diameter (DBH). Stem volume was calculated as $(DBH^2*Height)*(0.002)$.

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Table 1—Mean growth response after 3 years of trees treated at age 7, in a naturally regenerated North Carolina coastal plain upland. Means within a column followed by different letters are significantly different at P = 0.10, by protected LSMeans. "ANOVA" indicates the statistical analysis for each parameter across treatments, and "Fertilization" and "Thin X Fert" indicate the significance of the main effect or treatment interaction for each parameter. Thinning was not a significant main effect.

	- - - - - - - - - - - - - - - - - - - *Measures at Age 10*	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - - -
Treatment (Statistics)	Height (ft.)	DBH (in.)	Volume (cu. ft. per ac.)
Control	22.7 ab	2.43 a	353 a
Thinned	22.0 ab	2.44 a	317 a
Fertilized	23.8 ab	2.52 a	557 b
Thinned + Fertilized	24.6 b	2.82 b	660 c
(ANOVA)	F = 5.99, P = 0.025	F = 6.90, P = 0.018	F = 39.73, P=0.0002
(Fertilization)	P = 0.030	P = 0.070	P = 0.0001
(Thin X Fert)	P = 0.327	P = 0.233	P = 0.056
-	- - - - - - - - - - - *3-Year Cumulative Increment Age 7 to 10*	- - - - - - - - - - - - - -	
Control	4.2 a	0.33	266 a
Thinned	4.5 a	0.35	220 a
Fertilized	5.8 b	0.50	479 b
Thinned + Fertilized	6.1 b	0.70	538 b
(ANOVA)	F = 8.57, P = 0.011	F = 2.52, P = 0.145	F = 39.56, P = 0.0002
(Fertilization)	P = 0.010	P = 0.040	P = 0.0001
(Thin X Fert)	P = 0.972	P = 0.434	P = 0.086

Canopy cover was estimated with a spherical densiometer in mid-August 2000. Data were analyzed by the General Linear Model procedure, and when significant differences among treatments were found, means were separated by the LS Means procedure (SAS 1989).

RESULTS AND DISCUSSION

Differences in tree size and cover among the treatments were visually apparent 3 years after thinning and fertilization. Densiometer readings of canopy cover were, control 77 percent, fertilized 86 percent, thinned 56 percent, and thinned + fertilized 83 percent. Ground cover patterns, data not reported here, reflected the inverse of the densiometer readings, and trees were noticeably larger in the treatment plots than the controls. Given the demonstrated positive relationships between leaf area, as approximated by densiometer readings in this case, and productivity (Albaugh and others 1998), we would expect that the treatment plots with high canopy cover would be more productive.

There were no significant differences ($P = 0.10$) in height, DBH or estimated volume among treatment plots in May 1997 immediately post treatment. Three years after the treatments were applied, mean height, DBH and volume, and 3-year cumulative increments for these measures, differed significantly among treatments (table 1). The interaction between thinning and fertilization was only significant for the volume estimates (table 1). Blocking effects were significant at age 10 for all parameters ($P < 0.05$). In general, the control and thinned plots did not differ, and had smaller trees than the fertilized and thinned + fertilized plots, which were similar to each other. For all parameters measured, the thinning effect was not significant ($P > 0.10$), and the fertilization effect was significant (table 1).

The data suggest that height growth was more responsive to the treatments than diameter growth, and that thinning alone did not generate a substantial growth response, whereas fertilization did. Observations of the thinned only plots suggested that thinning in this stand resulted in site resources being made available to competing plants (herbaceous, woody shrubs [notably wax myrtle, *Myrica cerifera*], and stump sprouts of cut trees), without benefit to the residual stand. When thinning was coupled with fertilization, however, the residual stand was apparently able to capture a significant portion of the newly available and added site resources, and exhibit a positive growth response.

These types of interacting biotic and abiotic constraints to growth have been reported, and typically support the idea that thinning alone, when the residual stand is not immediately able to occupy the new space (typical of young stands), does not result in enhanced growth (Graney and Rogerson 1985, Kolb and others 1989, Romagosa and Robison 1999). However, when coupled with weed control and/or fertilization, the response can be substantial (Schuler and Robison, this issue). In the current study, fertilization alone resulted in increased growth for most parameters, and suggests that this low-cost silvicultural intervention may have good operational potential. Although thinning coupled with fertilization did not appreciably increase growth over fertilization alone, the data trends and significant interaction between these treatments (table 1) suggest that over time, the combined effect may be greater than either individual treatment.

The treatments in the current study do not indicate what the effect of thinning + weed control might have been, however other studies suggest that the positive aspects of density reduction can be realized in young stands when weed control is used (Pham 1988, Schuler and Robison, this issue). Further, it cannot be determined which fertilizer element was responsible for the positive effects recorded in this study, nor does this study reveal optimum rates or timing for fertilization. However, the results reported here suggest that substantial productivity gains may be realized in very young stands.

CONCLUSIONS

Fertilization alone and in combination with thinning nearly doubled the 3-year stand volume increment from age 7 to 10 in this study in young natural hardwoods. Thinning alone did not enhance growth in the 3 years post treatment. These findings suggest that early stand silvicultural interventions may substantially accelerate stand development and shorten rotation age, with clear operational potential. If through such practices, species composition and stem quality could also be improved, the benefits to timber production would be enhanced further.

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REFERENCES

Albaugh, T.J.; H.L. Allen; P.M. Dougherty; L.W. Kress; J.S. King. 1998. Leaf-area and above- and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science. 44: 317-328.

Dunn, M.A.; K.W. Farrish; J.C. Adams. 1999. Fertilization response in a natural bottomland hardwood stand in north-central Louisiana. Forest Ecology Management. 114: 261-264.

Farmer, R.E.; Jr., G.W. Bengtson; J.W. Curlin. 1970. Response of pine and mixed hardwood stands in the Tennessee Valley to nitrogen and phosphorus fertilization. Forest Science. 16: 130-136.

Gingrich, S.F. 1971. Management of young and intermediate stands of upland hardwoods. Res. Pap. Darby, PA: U.S. Department of Agriculture, Forest Service, NE Experiment Station, Upper NE-195. 26 p.

Graney, D.L.; T.L. Rogerson. 1985. Development of oak, ash and cherry reproduction following thinning and fertilization of upland hardwood stands in the Boston Mountains of Arkansas. In: Prosceedures. Third Southern Silvicultural Research Conference: 171-177.

Heitzman, E.; R.D. Nyland. 1991. Cleaning and early crop-tree release in northern hardwood stands: a review. Northern Journal of Applied Forestry. 8 (3): 111-115.

Johnson, J.E.; J.J. Bollig; R.A. Rathfon. 1997. Growth response of young yellow-poplar to release and fertilization. Southern Journal of Applied Forestry. 21(4): 175-179.

Kolb, T.E.; T.W. Bowersox; L.H. McCormick; K.C. Steiner. 1989. Effects of shade and herbaceous vegetation on first-year germination and growth of direct-seeded northern red oak, white ash, white pine, and yellow-poplar. Gen. Tech. Rep. NC-132: U.S. Department of Agriculture, Forest Service.

Pham, C.H. 1988. Thinning young, natural hardwood regeneration with broadcast herbicide application. In: R.L. Hay and others eds. Proceedings of the Central Hardwood Forest Conference; 1987 February 24-26; Knoxville, TN: 205-215.

Romagosa, M.A.; D.J. Robison. 1999. An evaluation of biological constraints to the early growth of natural hardwood regeneration on North Carolina Piedmont clearcuts. ,In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 39-42.

SAS (Statistical Analysis System). 1989. SAS/STAT User's Guide, version 6, 4th ed., Vols. 1 and 2. SAS Institute, Inc., Cary, NC.

EARLY THINNING IN BOTTOMLAND HARDWOODS

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Abstract—A 23-year-old sprout origin stand in the Congaree river bottom near Columbia S.C was commercially thinned in 1994 using standard "Leave Tree", "Trainer Tree", and "Corridor" methods. The stand consisted of 260-325 trees per acre and 28-31 cords per acre. There were 90-140 potential crop trees (30 to 40 percent commercial oaks) of different bottomland species, oaks (*Quercus* spp), sycamore (*Platanus occidentalis*), sweetgum (*Lyquidambar styraciflua*), green ash (*Fraxinus pennsylvania*), red maple (*Acer rubrum*), and sugarberry (*Celtis laevigata*). After 5 years of growth, the effect of thinning on residual crop tree quality was measured by number of epicormic sprouts, degree of logging damage, and vine occurrence. Five years after thinning the 28-year-old stand averages 70 crop trees per acre, 12.4 inches diameter and 2.35 logs commercial height. All thinning methods had twice the number of epicormic sprouts as did the control. Logging damage was the lowest in the trainer tree treatment. Vine occurrence on crop trees was reduced by thinning to half that of the controls (30 versus 60 percent), which is a considerable enhancement in the future quality of crop trees.

INTRODUCTION

Early thinnings in upland and bottomland hardwoods provide the landowner with economic return that would normally be lost to mortality (Gingrich 1971; Kellison and others 1988). These thinnings improve stand quality by changing species composition, selecting quality stems, improving tree spacing, and maintaining crown vigor of desired stems (Carvell 1971).

The thinning of bottomlands favors valuable high quality stems, such as cherry bark (*Quercus pagoda*) and Shumard (*Q. Shumardii*) oaks (Kennedy and Johnson 1984). Some other desirable commercial species to favor with thinnings are green ash, red maple, sweetgum, sugarberry and sycamore. Consideration should be taken to not favor a low quality stem of a high valued species over a high quality stem of a low valued species (Kennedy and Johnson 1984). A crop tree also should be selected based on the vigor and quality of the surrounding stems (Clatterback and others 1987). However, the removal of too many cull trees can leave the stand understocked (Gingrich 1971).

Thinning as early as ages 20-25 years can increase the growth potential and value of bottomland hardwoods on good sites and the increased market for hardwood pulpwood allows productive bottomland sites to be commercially thinned at such early ages (Kellison and others 1988). There is no standard method in thinning hardwoods as it is frequently based on the best judgement of the forester. However, such early thinnings can be marginally commercial if they result in degrade to residual crop trees or require too much time of a professional forester. In early 1993 local consulting foresters approached us concerning the advisability of early thinning in sprout origin bottomland hardwood stands (Personal communication. 1993. Angus Lafaye, Forester, Milliken Forestry, Columbia, SC). The objective of this study was to determine the most effective "standard" commercial thinning method relative to effects of thinning on the future value of residual crop trees in this particular young stand.

METHODS

Study Site

The study site is located in a young bottomland hardwood stand on the Congaree River (a red river) near Columbia, SC. The soil type is a well-drained loamy Typic Udifluvent of the Congaree series. The stand was a 23-year-old sprout origin stand that was KG-blade sheared in 1971. Before thinning the stand consisted of 260-325 trees per acre or 28-31 cords per acre, with 90-140 potential crop trees per acre (30 to 40 percent commercial oaks) of different bottomland species (oaks, sycamore, sweetgum, green ash, red maple, and sugarberry). The criteria for crop trees were that they be a commercial species, have a minimum of one log, of good bole form, minimal epicormic sprouting (less than 3 sprouts in the first log), and be a dominant or co-dominant tree. The stand has a site index (base age 50 years) of 85-95 feet for cherrybark oak.

Experimental Design

The thinning methods were done in a randomized complete block design with four 16-acre blocks containing 4-acre treatments of unthinned control, trainer tree, leave tree, and corridor thinning methods as described by Tinsley and Nix (1998). Each 16 acre block has a main skid trail (20 feet wide) marked down the center with treatments on either side. The control is an uncut area. Analysis of variance for a randomized complete block design was

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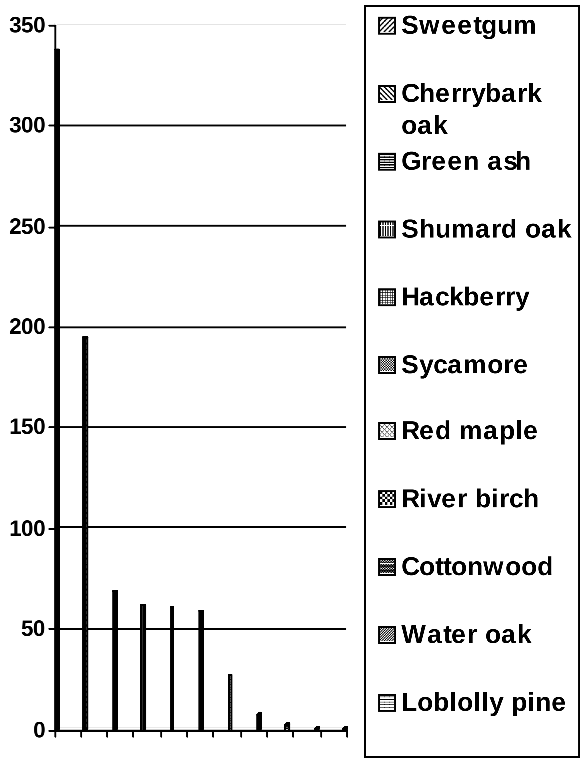

Figure 1— Species prevalence among crop trees (number of the 824 total sampled). Bars in graph from l-r match species list from top to bottom

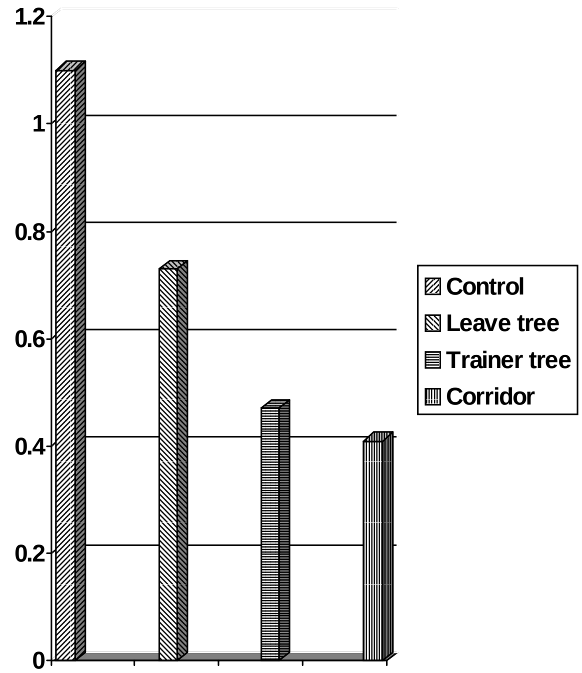

Figure 2— Number of vines on crop trees by thinning method.

performed to test the differences between treatment means (SAS Institute l998). When the treatment means were different Tukey's test at the .05 level of significance was used to test which means were different.

Measurements

A one-acre sampling area was marked in the center of each of the four acre treatment plots, thus, the sample area has a 104.3 feet treatment buffer on all sides. The sample trees were marked before measurements were taken to remove bias from the data. In the corridor treatment the sample crop trees were chosen right up to the edge of the cut strip in order to include the influence of the adjacent open area on future quality. For each crop tree the species, diameter, number of logs, the number of epicormic sprouts (first, second and third log), vine occurrence, vines present in the crown, and logging damage were tallied.

Thinning Methods

All thinning methods were marked to be commercial, at least 10 cords per acre were to be removed (about a 100 trees per acre averaging 8 inches diameter). The trainer tree treatment was designed to leave at least one cull tree near the crop tree to protect it from logging damage and shade out epicormic sprouting on the lower bole. The crop trees were located at 20 by 20 feet spacing (108 trees per acre) in keeping with the 60 percent residual stocking level for upland hardwoods of Gingrich (1971) with about 25 percent more trees per acre added for the more productive bottomland site.

The leave tree method removed all trees except for the crop trees. The same 20 by 20 feet spacing was allowed, but all trees other than crop trees were marked to be cut. If a crop tree was not present at 20 feet, then a reasonable crop tree within a 10 foot radius was left. This method left no protection for the crop trees from logging damage nor shade to suppress epicormic sprouting along the lower bole.

The corridor treatment removed one-third of the volume (about 100 trees per acre) in the cut strip. The forester marked a 20 foot wide cut strip and left a 40 foot wide uncut strip. The cut strips were marked in a 60-degree herringbone pattern to the main skid trail in an attempt to reduce logging damage that results from turning loads. The corridor treatment is an indiscriminate thinning method where crop trees are removed as well as culls.

Vine Control

In most bottomland sites, especially very fertile sites, wild grape vines (*Vitus* spp.) are a problem in the management of high quality crop trees (Smith 1986). Vines can dominate the crown of crop trees causing bad bole form and epicormic sprouting, especially when the vines and crop trees start off as sprouts together. Vines were very prevalent on this site (60 percent of crop trees were infested). Thinning can reduce the number of vines through severing their stems during mechanical harvesting. This is beneficial to the stand. The number and presence of vines in the crowns of crop trees were measured in all treatments.

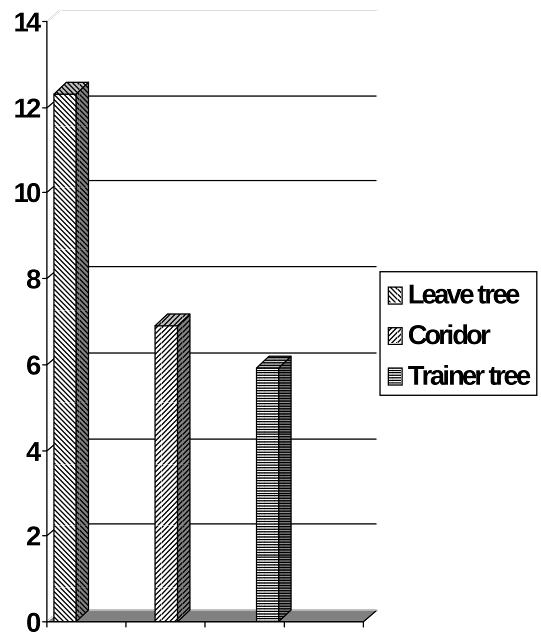

Figure 3— Percent of crop trees damaged from logging by thinning method.

Logging Damage
Thinning operations can be detrimental to the stand because of logging damage. Felling, backing, skidding, and turning with large equipment damage crop trees. This causes a decrease in the number, quality and value of crop trees. Logging damage is reduced through good communication and a well designed harvest plan (Smith 1986). This usually slows down production so an economic incentive (reduction in stumpage value) often is added to reduce careless errors. The objective of each thinning method was explained to the logger and the stumpage value was proportionally decreased to reduce the amount of logging damage that might be caused by haste to make up lost production. However, some logging damage is expected, so each residual crop tree sampled was examined for logging damage.

Epicormic Sprouts
Epicormic sprouts are a source of degrade in hardwood logs. The value of hardwood trees is determined by the grade. The log grade reflects the number and size of clear lumber cuts which can be made from a specific log (Kennedy and Johnson 1984). In opening the canopy the thinning operation may cause epicormic sprouting which will decrease the future financial return. Epicormic sprouts were counted for the first, second and third log of every crop tree sampled.

RESULTS

Residual Crop Trees
The residual stand has an average of 50-90 high quality crop trees per acre depending on the thinning method. Five years after thinning, losses to logging damage and sprout degrade resulted in reducing the leave tree plots to 51.5 crop trees per acre, the corridor method to 81.5, and the trainer tree method to 90.4. This is a drastic reduction in the number of crop trees than that projected before the thinning (at least 100 per acre were to be left). These losses can be partially explained by the premeasurement rejection of crop trees having profuse epicormic sprouting (more than 6 sprouts in the butt log). The remaining crop trees have an average diameter of 12.4 inches and an average height of 2.35 logs. A total of 824 crop trees were sampled and consisted of 41 percent sweetgum, 24 percent cherrybark oak, 8 percent Shumard oak, and 27 percent others (figure 1). An analysis was done to test interactions between treatments and diameter and treatments and species. These interactions were not significant at the 0.05 level.

Vine Occurrence
The number of vines per crop tree was reduced by the thinning treatments. The control trees had nearly twice as many vines as did those of the thinnings (figure 2). Vines were in the crowns of unthinned crop trees nearly two times more often than those thinned (60 versus 30 percent). The control significantly differs from the thinnings which do not differ. The use of heavy machinery in thinnings silviculturally enhanced the future quality of crop trees by reducing the presence of live vines in the crowns.

Logging Damage
Logging damage was kept to a minimum by the following factors: 1) good communications, 2) well-designed harvest plan, and 3) reduced stumpage values charged the logger for less productive methods (Tinsley and Nix 1998). The leave tree thinning damaged 12 percent of the crop trees, the other methods did half of that much damage (figure 3). The leave tree and trainer tree methods differed because the leave tree had no protection from machinery. The trainer tree and corridor thinnings inherently reduce logging damage to residual crop trees.

Epicormic Sprouting
The thinnings caused nearly 3 times more epicormic sprouts on the first log than occurred in the control (figure 4). Similar results occurred on the second and third logs where they existed. The control had significantly fewer sprouts than any of the thinnings. All of the thinnings apparently increased the amount of sunlight in the stand which stimulated epicormic sprouting (Brown and Kormanik 1970). The effects of the thinnings on sprout numbers did not differ. Of the crop tree species Shumard oak had nearly three times the number of sprouts as the other species, a significant difference (figure 5).

Diameter Growth
The average diameter of crop trees in the leave tree thinning was nearly 13 inches, but did not differ from the control. A regression analysis was run to test the correlation

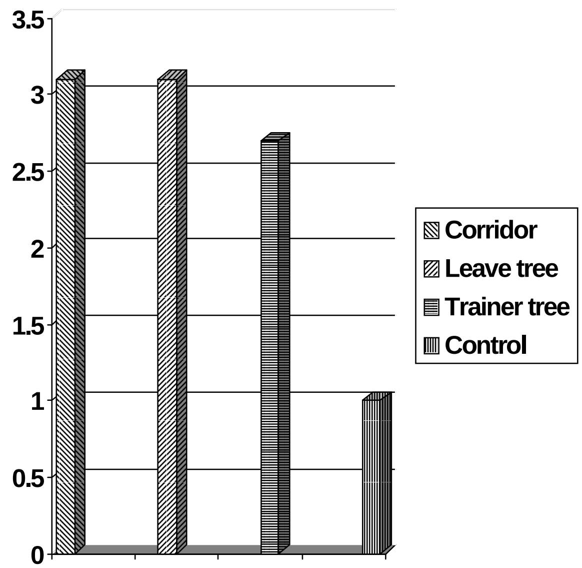

Figure 4— Number of epicormic sprouts on the first log by thinning method.

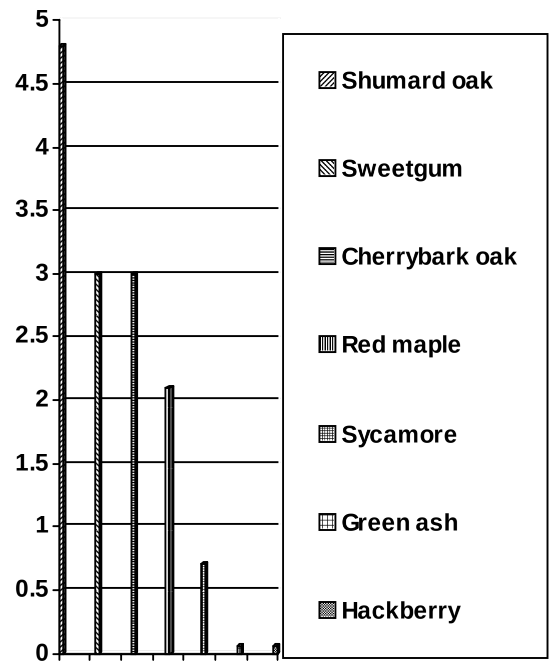

Figure 5— Number of epicormic sprouts on the first log by species.

between diameter and number of epicormic sprouts on the first log. There was a significant negative correlation that showed as the diameter increased the number of epicormic sprouts on the first log decreased, further indication of the negative effect of vigor on epicormic sprouting (Brown and Kormanik 1970).

CONCLUSIONS

All thinning methods met the objective of being a commercial harvest of 10 cords per acre or more and left 100 crop trees per acre. Although the leave tree method was the most productive harvest at 16 cords per acre, five years after thinning it has the greatest reduction of crop trees (over half) due to logging damage and epicormic sprouting. All thinning methods were detrimental to the future stand, producing nearly three times as many epicormic sprouts on the first log as occurred in the control. These sprouts resulted in down grading the number of crop trees left after thinning, reducing the leave tree thinning crop tree numbers by as much as 30 percent.

The control of vines appeared equally as good with the corridor method as the others and it was the most efficient to conduct. However, the corridor method significantly reduced the number of crop trees per acre since a third are removed and another 6 percent were lost to epicormic sprouting. There is no real explanation for the reduced number of vines in the corridor method since machinery activity was confined to the 20 foot wide cut strip. The least amount of logging damage occurred with the trainer tree method, but it was the hardest to mark and least productive for the loggers. The corridor and trainer tree methods proved to be the best thinning methods in this study, but the decision to use either of these methods should be based on careful consideration of the conditions of the existing stand.

If the stand has adequate desirable high quality stems (140 or more per acre) then the corridor method can be used if a target of at least 100 residual crop trees per acre averaging 12 inches diameter is desired. If the existing stand has at least 110 crop trees per acre, then the trainer tree method can be used. Because of the 12 percent logging damage to crop trees, and the 30 percent reduction in crop trees for epicormic sprouting, the leave tree thinning method should not be used in stands such as in this study unless at least 140 desirable crop trees can be marked to be left per acre. The effects of thinning on crop tree quality and growth in these study plots will be monitored again in the future.

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REFERENCES

Brown, C.L.; Kormanik, P.P. 1970. The influence of stand disturbance on epicormic branching. In: Silviculture and Management of Southern Hardwoods, 19th Annual Forestry Symposium. Baton Rouge, LA: LSU: 103-112.

Carvell, Kenneth L. 1971. Silvicultural aspects of intermediate cuttings. In: Proceedings, Oak Symposium; 1971 August 16-20; Morgantown, West Virginia. Upeer Darby, PA: U.S. Department of Agriculture, Forest Service, NE Forest Experiment Station: 60-64.

Clatterbuck, W.K.; Olliver, C.D.; Burkhardt, E.C. 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: spacing is the key. Southern Journal of Applied Forestry 11(3): 158-161.

Gingrich, S.F. 1971. Stocking, growth, and yield of oaks stands. In: Proceedings, Oak Symposium; 1971 August 16-20; Morgantown, West Virginia. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, NE Forest Experiment Station: 65-73..

Kellison, R.C.; Martin, J.P.; Hansen, G.D.; Lea, R. 1988. Regenerating and managing natural stands of bottomland hardwoods. APA 88-A-6. Bottomland Hardwood Management Taskforce, Southeastern Technical Division, American Pulpwood Association, Inc. 26 p.

Kennedy, H.E.; Johnson, R.L. 1984. Silvicultural alternatives in bottomland hardwoods and their impact on stand quality. In: Proceedings, 14th Annual Southern Forest Economics Workshop; 1984 March 13-15; Memphis, TN. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 6-18.

SAS Institute 1999. SAS User's Guide: Statistical Version 6. Carey, NC. 484 p.

Smith, D.M. 1986. The Practice of Silviculture. New York: John Wiley & Sons, Inc. 525 p.

Tinsley, M.B.; Nix, L.E. 1998. Early thinnings in a young, sprout-origin, bottomland hardwood stand in South Carolina. In: Proceedings, Ninth Biennial Southern Silvicultural Research Conference; 1997 February 25-27; Clemson, SC. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 170-174.

FOURTH-YEAR EFFECTS OF THINNING ON GROWTH AND EPICORMIC BRANCHING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE IN WEST-CENTRAL ALABAMA

James S. Meadows and J.C.G. Goelz[1]

Abstract–Four thinning treatments were applied to a 60-year-old, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in late summer 1994: (1) unthinned control; (2) light thinning to 70-75 percent residual stocking; (3) heavy thinning to 50-55 percent residual stocking; and (4) B-line thinning to desirable residual stocking for bottomland hardwoods, as recommended by Putnam and others (1960). The thinning operation consisted of a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Prior to thinning, stand density averaged 196 trees and 121 square feet of basal area per acre. Average stand diameter was 10.7 inches, while stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased average stand diameter to 13.5 inches, and reduced stocking to 69 percent. Heavy thinning reduced stand density to 49 trees and 64 square feet of basal area per acre, increased average stand diameter to 15.5 inches, and reduced stocking to 52 percent. Putnam's B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased average stand diameter to 15.6 inches, and reduced stocking to 70 percent. Only small increases in stand-level basal area and average stand diameter were observed in the thinned areas 4 years after thinning. Thinning significantly increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. These increases in diameter growth were most pronounced among red oaks. Thinning produced only small increases in the number of new epicormic branches on the butt logs of residual trees, averaged across all species. Epicormic branching varied widely across both species and crown classes. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. Heavy thinning appears to have produced the best combination of stand-level growth and individual-tree diameter growth, with minimal increases in epicormic branching, especially among red oak crop trees.

INTRODUCTION

Profitable management of hardwood stands for sawtimber production depends not only on maintenance of satisfactory rates of growth, but also on successful development and maintenance of high-quality logs. In general, a combination of thinning and improvement cutting can be used in most mixed-species bottomland hardwood forests to: (1) enhance growth of individual residual trees, (2) improve stand-level growth, (3) maintain and improve bole quality of residual trees, and (4) improve species composition of the stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees, as has been reported for several hardwood forest types, such as upland oaks in the Midwest (Hilt 1979, Sonderman 1984b), cherry-maple (*Prunus* spp.-*Acer* spp.) in the Allegheny Mountains (Lamson 1985, Lamson and Smith 1988), and mixed Appalachian hardwoods (Lamson and others 1990). In general, the heavier the thinning, the greater the diameter growth response of individual trees. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished, even though diameter growth and volume growth of individual residual trees are greatly enhanced. In very heavily thinned stands, site occupancy may be less than optimum because the stand does not fully realize the potential productivity of the site. Recommended minimum residual stocking levels necessary to maintain satisfactory stand-level growth and to ensure full occupancy of the site are 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in cherry-maple stands (Lamson and Smith 1988). Residual stand density equivalent to 52 percent stocking in a young water oak (*Quercus nigra* L.) plantation appeared to be sufficient to promote adequate basal area growth following thinning, whereas a residual stocking level of 33 percent created a severely understocked stand that will be unable to fully occupy the site for many years to come (Meadows and Goelz 2001).

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Degradation of bole quality of residual trees is also sometimes associated with increased thinning intensity. For example, the number and size of both living and dead limbs on the boles of residual upland oak trees increased significantly as residual stocking decreased (Sonderman 1984a). On the other hand, Sonderman and Rast (1988) found that the production of epicormic branches on residual oak stems decreased with increasing thinning intensity. In stands thinned from below, the proportion of dominant and codominant trees in the residual stand increases as the intensity of thinning increases. These vigorous, upper-crown-class trees are less likely to produce epicormic branches than are less-vigorous, lower-crown-class trees (Meadows 1995). Consequently, a well-designed thinning should improve average bole quality throughout the residual stand. In many stands, however, there may be a trade-off between improved diameter growth and the potential for adverse effects on bole quality of residual trees, as thinning intensity increases and residual stand density decreases.

A combination of thinning and improvement cutting can also be used to improve species composition of mixed-species hardwood stands (Meadows 1996). In general, the goal is to decrease the proportion of low-value species and thus increase the proportion of high-value species. Although most important at the time of the first thinning, improvement of species composition should be a major consideration whenever a partial cutting is performed in mixed-species hardwood stands.

These four components of thinning, increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, enhanced bole quality, and improved species composition, are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, thinning regimes should be designed to optimize the value of the stand, as determined by these four components. However, because maximization of all four components is not possible, some trade-offs in expected benefits must be accepted.

Research on thinning in southern bottomland hardwood forests is lacking. Existing guidelines, such as those recommended by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience and observation rather than on actual research results. Successful management of southern bottomland hardwood stands for high-quality sawtimber production requires quantitative thinning guidelines that include recommendations on: (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) marking rules designed to optimize stand value throughout the rotation.

To address this need for quantitative thinning guidelines, we are establishing a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. All studies in the series use the same study design, treatments, and methods. The study reported here is the first in the series. All individual studies within the series are designed to determine the effects of several levels of thinning on: (1) stand-level growth, development, and yield, and (2) growth and bole quality of individual trees. Results from the entire series of 10-12 studies will be combined to: (1) develop practical guidelines for the intermediate management of southern bottomland hardwood stands, (2) evaluate the applicability of various levels of recommended residual stocking across a wide variety of site and stand conditions, and (3) develop a growth and yield model for managed stands of southern bottomland hardwoods.

METHODS

Study Area

The study is located within the floodplain of the Tombigbee River in northeastern Sumter County near the community of Warsaw in west-central Alabama. The land is owned by Gulf States Paper Corporation. The site is subject to periodic flooding during the winter and spring months, but floodwaters generally recede within a few days.

Soils across most of the study site belong to the Ochlockonee series, but there are small areas of Falaya soils in the lower areas. The Ochlockonee soils are well-drained, but the Falaya soils are somewhat poorly drained. Infiltration and permeability rates are moderate to rapid across the site. Both soils have moderate-to-high natural fertility and high available water capacity. Texture in the upper soil horizon across the study area is silt loam to fine sandy loam. Soil pH is very strongly acid and ranges from 4.5 to 5.5 across the site. Broadfoot (1976) reported average site indexes of the Ochlockonee soils to be 110 feet at 50 years for water oak and 112 feet at 50 years for sweetgum, and estimated site index for cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) to range from 100 to 120 feet at 50 years. The Falaya soils are only slightly less productive. Site indexes are reported to average 101 feet at 50 years for water oak, 111 feet at 50 years for sweetgum, and 108 feet at 50 years for cherrybark oak (Broadfoot 1976).

The study area is located within a 74-acre stand composed primarily of red oak, sweetgum, and hickory (*Carya* spp.). Principal red oak species are cherrybark and water oaks, with scattered trees of willow oak (*Quercus phellos* L.), southern red oak (*Q. falcata* Michx.), and Shumard oak (*Q. shumardii* Buckl.). White oak species include white oak (*Q. alba* L.), overcup oak (*Q. lyrata* Walt.), and swamp chestnut oak (*Q. michauxii* Nutt.). The stand was about 60 years old at the time of study installation. There was no evidence of previous harvesting activity in the stand. Based on an inventory by Company personnel in 1993, sawtimber volume averaged 6,520 board feet per acre (Doyle scale), of which 81 percent was red oak, and pulpwood volume averaged 12.5 cords per acre (Personal communication. Sam Hopkins. 1993. Research Manager, Gulf States Paper Corporation, P.O. Box 48999, Tuscaloosa, AL 35404).

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the U.S. Forest Service's Northeastern Forest Experiment Station (Marquis and others 1990). Each individual treatment was uniformly applied across a 2.0-acre, rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One, 0.6-acre, rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), providing a 1-chain buffer around each. The entire study covered an area of 24 acres.

Treatments

Treatments were defined as four levels of residual stocking, based on a stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (1) an unthinned control, (2) light thinning to 70 to 75 percent residual stocking, (3) heavy thinning to 50 to 55 percent residual stocking, and (4) B-line thinning to desirable residual stocking following partial cutting in well-managed, even-aged southern bottomland hardwoods, as recommended by Putnam and others (1960).

A combination of low thinning and improvement cutting was used to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), formed the cutting priority for each treatment. Trees were removed from the cutting stock and cull stock classes first and then from the reserve growing stock class, when necessary, until the target residual stocking was met.

Three replications of the four treatments were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1994. A contract logging crew directionally felled all trees with a mechanized feller and used rubber-tired skidders to remove the merchantable products in the form of longwood. Most of the material cut was utilized as pulpwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. We recorded species, diameter at breast height (dbh), crown class, and tree class on all trees greater than or equal to 3.5 inches dbh. Based on hardwood tree classes, we marked the stand for thinning to the target residual stocking prescribed for each treatment. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section were recorded on those trees designated as “leave” trees. We also measured sawtimber merchantable height, height to the base of the live crown, and total height on a subsample of “leave” trees. Crown class, dbh, and the number of epicormic branches on each 16-foot log section were measured annually for the first 4 years after thinning. Previous results were reported by Meadows and Goelz (1998, 1999).

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the stand averaged 196 trees and 121 square feet of basal area per acre, with a quadratic mean diameter of 10.7 inches. The average stocking of 107 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). We found no significant differences among treatment plots in any preharvest characteristics. Although the stand was dense, most of the upper-crown-class trees were healthy and exhibited few symptoms of poor vigor, such as crown deterioration, loss of dominance, or the presence of numerous epicormic branches along the boles. Little sunlight reached the forest floor, except in small gaps created by the death of scattered trees throughout the stand. The stand needed thinning but was not stressed to the point of stagnation at the time of study installation.

This even-aged, mixed-species stand was dominated by red oak, hickory, and sweetgum. Red oaks (primarily cherrybark and water oaks, but with lesser numbers of willow, southern red, and Shumard oaks) accounted for about 45 percent of the basal area of the preharvest stand. Red oaks dominated the upper canopy and had a quadratic mean diameter of 16.1 inches. Mockernut hickory [*Carya tomentosa* (Poir.) Nutt.] and shagbark hickory [*C. ovata* (Mill.) K. Koch] together accounted for about 25 percent of the basal area. Hickories were found primarily in the mid-canopy, but scattered individuals occurred in the upper canopy. Sweetgum made up about 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white, overcup, and swamp chestnut oaks, green ash (*Fraxinus pennsylvanica* Marsh.), American elm (*Ulmus americana* L.), and winged elm (*U. alata* Michx.). Along with small hickories and sweetgum, American hornbeam (*Carpinus caroliniana* Walt.), red mulberry (*Morus rubra* L.), black tupelo (*Nyssa sylvatica* Marsh.), and various maples dominated the understory.

Table 1—Stand conditions and individual-tree diameter growth 4 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Mortality	Basal area	Basal area growth	Stocking	Quadratic mean diameter	Cumulative diameter growth
	No./acre	Pct	Sq ft/acre	Sq ft/acre	Pct	In.	In.
Unthinned	169 a	8.2 a	121 a	4 ab	105 a	11.4 b	0.33 c
Light thinning	78 b	6.0 a	85 bc	3 b	70 b	14.3 ab	0.58 b
Heavy thinning	49 c	0.0 a	70 c	6 a	57 c	16.6 a	0.69 ab
B-line thinning	59 bc	9.2 a	91 b	5 ab	74 b	16.9 a	0.78 a

Table 2—Total number and number of new epicormic branches on the butt logs and on upper logs of residual trees 4 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	---------------*Butt logs*---------------		--------------*Upper logs*-------------	
	Total epicormic branches	New epicormic branches	Total epicormic branches	New epicormic branches
Unthinned	6.7 a	1.1 b	15.1 a	4.0 a
Light thinning	4.2 a	3.1 a	16.5 a	7.8 a
Heavy thinning	3.8 a	2.7 a	13.8 a	6.5 a
B-line thinning	4.8 a	3.1 a	14.6 a	7.3 a

Stand Development Following Thinning

Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased quadratic mean diameter to 13.5 inches, and reduced stocking to 69 percent. It removed 62 percent of the trees and 31 percent of the basal area. Heavy thinning reduced density to 49 trees and 64 square feet of basal area per acre, increased quadratic mean diameter to 15.5 inches, and reduced stocking to 52 percent. It removed 73 percent of the trees and 43 percent of the basal area. B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased quadratic mean diameter to 15.6 inches, and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average dbh of trees removed during the logging operation ranged from 7.1 inches in the light thinning treatment to 8.3 inches in the B-line thinning treatment. Overall average dbh of trees removed was 8.0 inches.

Thinning also improved species composition of the residual stand. All thinning treatments increased the proportion of red oak and decreased the proportions of both sweetgum and hickory within the residual stand. Most of the sweetgum and hickory removed from the stand were lower-crown-class trees and were utilized as pulpwood.

During the 4 years following thinning, we observed a small amount of mortality in all of the plots, except those subjected to heavy thinning (table 1). Most of the mortality occurred as a result of windthrow. These decreases in the number of trees per acre during the 4 years following thinning were not significantly different among treatments.

Stand-level basal area growth and increases in stocking and quadratic mean diameter indicate that the stand may be recovering faster from heavy thinning and B-line thinning than from light thinning (table 1). We measured only small increases in stand-level basal area in the lightly thinned and unthinned stands during the 4 years following thinning. However, larger increases in basal area were found as a result of heavy thinning and B-line thinning. In fact, cumulative basal area growth in the heavily thinned stand was significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning, a situation not found in earlier measurements (Meadows and Goelz 1998). A similar trend was observed for changes in stocking percent among the four treatments (table 1), but these increases were not statistically significant 4 years after thinning. All treatments also produced increases in quadratic mean diameter (table 1), with heavy thinning and B-line thinning again resulting in the largest increases (1.1 inches and 1.3 inches, respectively), as compared to 0.6 inches and 0.8 inches in the unthinned and lightly thinned stands, respectively. Although these results follow the same trend as that observed for stand-level basal area growth, these increases in quadratic mean diameter did not differ significantly among the four treatments.

Diameter Growth

We found significant differences between all three of the thinning treatments and the unthinned control in cumulative diameter growth of individual trees 4 years after treatment (table 1). Depending upon treatment, thinning increased diameter growth of residual trees by 76 to 136 percent when compared to the unthinned control. For the first time since study installation, we also detected differences among the three levels of thinning. Cumulative diameter growth of residual trees 4 years following B-line thinning was

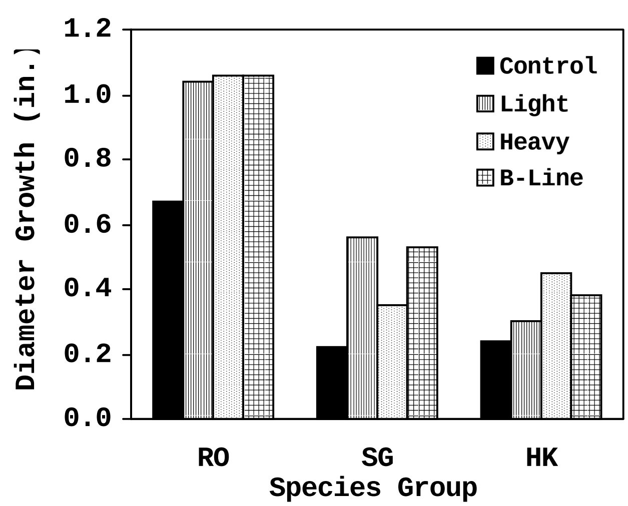

Figure 1–Diameter growth of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

significantly greater than diameter growth of residual trees following light thinning. As the study continues, we expect to find even greater differences among the three levels of thinning.

Individual species groups varied significantly in their diameter growth response to the four treatments (figure 1). All three levels of thinning increased cumulative diameter growth of residual red oaks by about 55 percent after 4 years (a little more than 1.0 inches as compared to about 0.7 inches for red oaks in the unthinned control). All three thinning treatments also greatly increased cumulative diameter growth of residual sweetgum trees, but response was less than that observed among red oaks. Cumulative diameter growth of hickory was relatively poor, but the largest increases occurred in response to heavy thinning and B-line thinning.

None of the three levels of thinning significantly affected cumulative diameter growth of dominant trees, when averaged across all species, but heavy thinning and B-line thinning increased cumulative diameter growth of codominant trees by about 33 percent over the unthinned control (figure 2). Both the heavy and B-line thinning treatments also nearly doubled cumulative diameter growth of trees in the intermediate crown class. Light thinning failed to produce significant increases in cumulative diameter growth of trees in any of these three crown classes. Cumulative diameter growth response of suppressed trees 4 years after thinning was erratic across treatments primarily because thinning removed most of these small inferior trees.

It is clear that all three levels of thinning successfully increased cumulative diameter growth of residual trees 4 years after thinning. The largest increases in diameter growth as a result of thinning were observed among red oaks in the codominant crown class. In most situations, codominant red oaks were classified as crop trees and were considered to be the most desirable trees for high-quality sawtimber production. Our thinning guidelines were designed to favor these trees and, at least so far, we appear to have been successful in enhancing the diameter growth of the most desirable trees in the stand.

Epicormic Branching

The production of epicormic branches along the merchantable boles of residual trees can be a serious problem in thinning hardwood stands. These epicormic branches cause defects in the underlying wood and can reduce both log grade and subsequent lumber value.

Because we removed most of the trees of poor bole quality during the thinning operation, residual trees in the thinned plots, on average, had fewer epicormic branches on the butt log 4 years after thinning than did trees in the unthinned control, but these differences were not statistically significant (table 2). However, all levels of thinning significantly increased the production of new epicormic branches on the butt log, even though trees in all thinning treatments averaged only about three new branches during the first 4 years after thinning. Epicormic branching on upper logs was uniformly high, regardless of treatment (table 2). Production of new epicormic branches varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many others produced only a few. Low-vigor trees, on the other hand, generally produced many new epicormic branches. Production of new epicormic branches, especially on the butt log, seems to be a delayed consequence of thinning. Meadows and Goelz (1998) reported that trees in all treatments averaged less than one new epicormic branch during the first year after treatment in this study. Our subsequent observations indicate that the majority of new epicormic branches were produced during the second year and that production of new branches during the third and fourth years was negligible. However, most new epicormic branches produced during the first 3 years survived through the fourth year.

Wide variation was found among species groups in the number of new epicormic branches produced on the butt log during the 4 years following thinning (figure 3). For

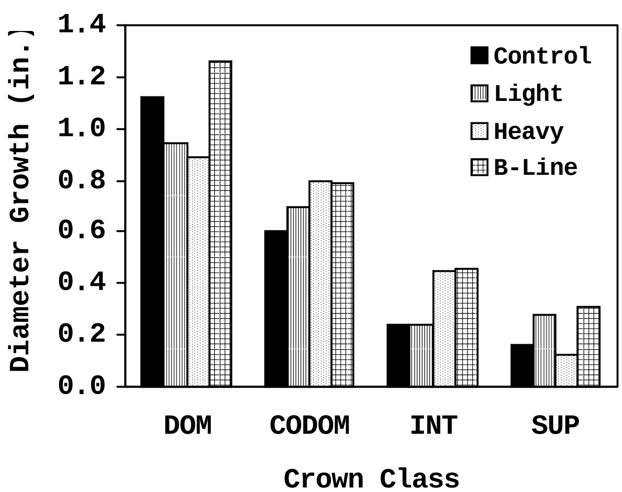

Figure 2–Diameter growth of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

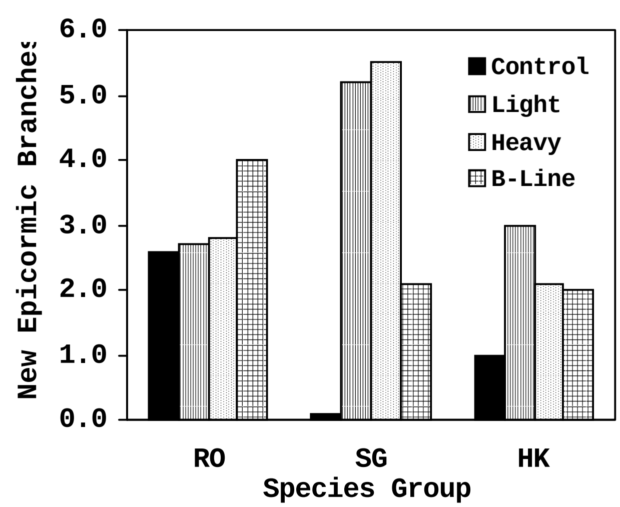

Figure 3–Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

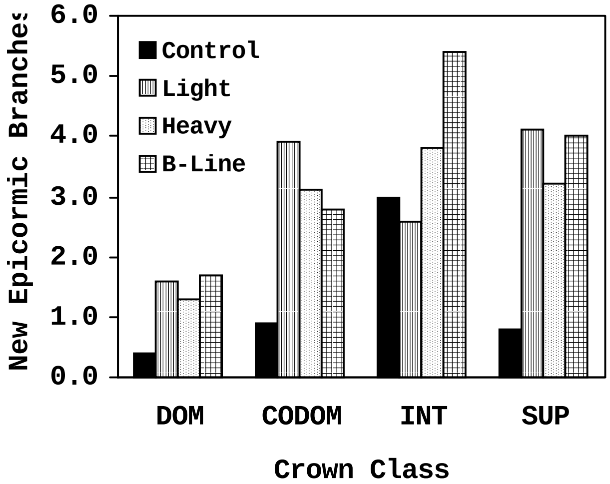

Figure 4–Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

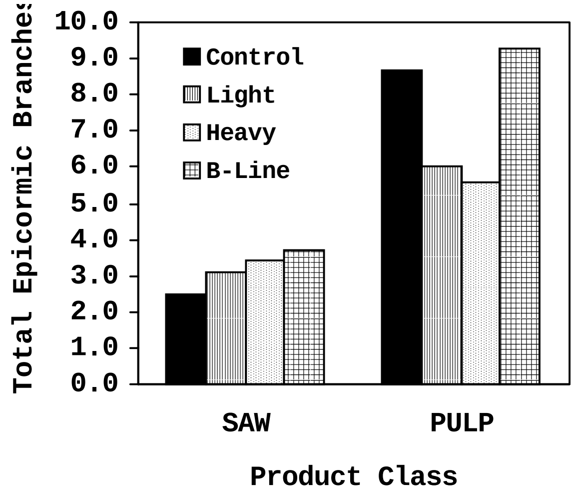

Figure 5–Total number of epicormic branches on the butt logs of residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

example, only B-line thinning increased the production of new epicormic branches on the butt logs of red oaks. In contrast, all levels of thinning greatly increased the production of new epicormic branches on the butt logs of sweetgum trees and more than doubled the number of new epicormic branches on the butt logs of hickories. The observation that the majority of these new branches were produced during the second year following thinning held true across all three species groups. It is important to note that heavy thinning had no significant effect on the production of new epicormic branches on the butt logs of red oaks, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching. Nearly all of the residual red oaks in the heavily thinned stand were high-vigor, upper-crown-class trees that are generally less likely to produce epicormic branches than are trees in poor health.

Production of new epicormic branches on the butt log also varied among crown classes, across all species (figure 4). In general, new epicormic branches were more frequent on the boles of lower-crown-class trees than on the boles of upper-crown-class trees, especially for trees in the thinned stands. These results support the hypothesis advanced by Meadows (1995) that the tendency for an individual hardwood tree to produce epicormic branches in response to some disturbance or stress is controlled by the species and initial vigor of the particular tree. Meadows (1995) noted that hardwood species vary greatly in their likelihood to produce epicormic branches and provided a classification of the susceptibility of most bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the mechanism that controls the production of epicormic branches when a tree is subjected to some type of disturbance or stress. It follows, then, that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Our observations in this study that epicormic branching varied not only by species but also among crown classes strongly support these hypotheses.

When assessing the effects of thinning on epicormic branching, the most important consideration, however, is the total number of epicormic branches found on the butt logs of the crop trees; these are the trees that are favored during the thinning operation and are most likely to produce high-quality sawtimber. Sawtimber trees in the thinned plots averaged 0.6 to 1.2 more epicormic branches on the butt log than sawtimber trees in the unthinned control, when averaged across all species (figure 5). However, these slight increases were not statistically significant. Both light thinning and heavy thinning actually significantly reduced the average number of epicormic branches on the butt logs of pulpwood trees. This reduction may be misleading because we removed most of the pulpwood trees of poor bole quality during the thinning operation.

To carry the analysis one step further, none of the three levels of thinning had a significant effect on the total number of epicormic branches on the butt logs of red oak sawtimber trees 4 years after thinning (figure 6). Red oak sawtimber trees, regardless of treatment, averaged fewer than five epicormic branches on the butt log, generally not enough to result in a reduction in log grade. Sawtimber-sized red oak trees with healthy dominant or codominant crowns apparently are not very susceptible to the production of new epicormic branches following even heavy thinning.

CONCLUSIONS

Stand-level growth and recovery appear to have been somewhat faster after heavy thinning and B-line thinning than after light thinning. In fact, cumulative basal area growth in the heavily thinned stand is now significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning. Similar, but not statistically significant,

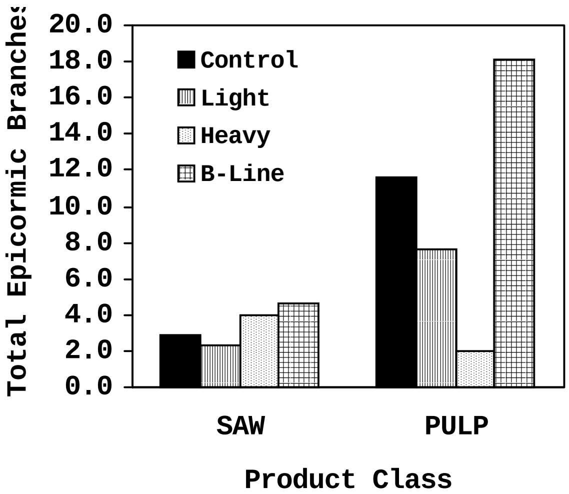

Figure 6–Total number of epicormic branches on the butt logs of red oak residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

increases in both stocking and quadratic mean diameter were observed after both heavy thinning and B-line thinning when compared to light thinning and the unthinned control. Thinning increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. Diameter growth response to thinning varied among species groups, with the most pronounced effect observed in red oaks. In fact, all levels of thinning increased cumulative diameter growth of residual red oaks by about 55-58 percent. None of the thinning treatments increased diameter growth of dominant trees, but heavy thinning and B-line thinning increased growth of codominant trees by about 33 percent.

All levels of thinning increased the production of new epicormic branches on the butt logs of residual trees, when averaged across all species, but these increases were relatively small. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. In fact, sawtimber-sized red oaks averaged fewer than five epicormic branches on the butt log 4 years after thinning. This level of epicormic branching is generally not enough to cause a reduction in log grade.

It appears at this time that heavy thinning created a combination of stand density and structure that best promoted rapid stand-level growth and rapid individual-tree diameter growth, with minimal adverse effects on epicormic branching and bole quality of residual trees, especially among red oak crop trees. Heavy thinning removed nearly all of the small-diameter, low-vigor, lower-crown-class trees, whereas the other levels of thinning retained larger proportions of these inferior trees. Consequently, heavy thinning concentrated diameter growth on large, healthy trees that contributed greatly to stand-level growth and minimized the production of new epicormic branches. Both B-line thinning and light thinning retained sufficient numbers of lower-crown-class trees to impede stand-level growth and to increase the risk of epicormic branching.

ACKNOWLEDGMENTS

We express appreciation to Gulf States Paper Corporation for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Sam Hopkins, John Foster, John Tiley, Harry Labhart, John Bryant, and Warren Eatman, all of Gulf States Paper Corporation, for their continuing assistance in this study.

LITERATURE CITED

Broadfoot, Walter M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3):103-104.

Goelz, J.C.G.; Meadows, J.S. 1997. Stand density management of southern bottomland hardwoods. In: Meyer, Dan A., ed. Proceedings of the 25th annual hardwood symposium; 25 years of hardwood silviculture: a look back and a look ahead; 1997 May 7-10; Cashiers, NC. Memphis, TN: National Hardwood Lumber Association: 73-82.

Hilt, Donald E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Johnson, Robert L. 1981. Wetland silvicultural systems. In: Jackson, Ben D.; Chambers, Jim L., eds. Timber harvesting in wetlands: 30th annual forestry symposium. Baton Rouge, LA: Louisiana State University, Division of Continuing Education: 63-79.

Lamson, Neil I. 1985. Thinning increases growth of 60-year-old cherry-maple stands in West Virginia. Res. Pap. NE-571. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Lamson, Neil I.; Smith, H. Clay. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Lamson, Neil I.; Smith, H. Clay; Perkey, Arlyn W.; Brock, Samuel M. 1990. Crown release increases growth of crop trees. Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Marquis, Dave; Smith, Clay; Lamson, Neil [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. [Warren, PA]: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

McKnight, J.S. 1958. Thinning stands of water oaks. In: Management of bottomland forests: Proceedings of the seventh annual forestry symposium; 1958 April 10-11; [Baton Rouge, LA]. Baton Rouge, LA: Louisiana State University, School of Forestry: 46-50.

Meadows, James S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, Glenn; Meyer, Dan, eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the twenty-third annual hardwood symposium; 1995 May 17-20; Cashiers, NC. [Memphis, TN]: National Hardwood Lumber Association: 19-25.

Meadows, James S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Clemson, SC: Consortium for Research on Southern Forested Wetlands, Clemson University: 98-101.

Meadows, James S.; Goelz, J.C.G. 1998. First-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site. In: Waldrop, Thomas A., ed. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 188-193.

Meadows, James S.; Goelz, J.C.G. 1999. Third-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site in west-central Alabama. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 87-93.

Meadows, James S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1):31-39.

Putnam, John A.; Furnival, George M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

Rast, Everette D.; Sonderman, David L.; Gammon, Glenn L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

Sonderman, David L. 1984a. Quality response of even-aged 80-year-old white oak trees after thinning. Res. Pap. NE-543. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Sonderman, David L. 1984b. Quality response of 29-year-old, even-aged central hardwoods after thinning. Res. Pap. NE-546. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.

Sonderman, David L.; Rast, Everette D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

SIXTH-YEAR RESULTS FOLLOWING PARTIAL CUTTING FOR TIMBER AND WILDLIFE HABITAT IN A MIXED OAK-SWEETGUM-PINE STAND ON A MINOR CREEK TERRACE IN SOUTHEAST LOUISIANA

Brian Roy Lockhart and Norwin E. Linnartz[1]

Abstract—Hardwood management has primarily focused on highly productive river bottom and upland sites. Less is known about hardwood growth and development on terrace sites. Such sites are usually converted to other uses, especially pine plantations. The objectives of this study, implemented in a minor creek terrace in southeast Louisiana, were to describe changes in stand composition and structure following partial cutting for 3 different management objectives: (1) maximize timber production, (2) maximize wildlife habitat, and (3) to improve timber production and wildlife habitat. Stand composition in 1985 prior to treatment was heavy to oak (72 percent based on importance values) compared to sweetgum (10 percent) and pine (16 percent). Greater diameter growth occurred in the treated plots compared to control 6 years after cutting. Diameter growth differences were also found between crown classes and species groups. Few differences were found in basal area growth between the treatments and the controls while stocking in the treated plots increased relative to the controls. Results indicate that hardwoods will respond to partial cutting on terrace sites, making hardwood or mixed pine-hardwood management options viable.

INTRODUCTION

Bottomland hardwood forest cover types (oak-gum-cypress and elm-ash-cottonwood) cover about 34 percent, or 4.7 million acres, of Louisiana's forested land based on the last U.S. Forest Service state forest inventory (Vissage and others 1991). Combined with the upland hardwood types (oak-hickory and oak-pine), hardwood-dominated forests cover 8.7 million acres or 63 percent of Louisiana's forested land (33 percent of Louisiana's total land base; Vissage and others 1991). Current hardwood acreage estimates are unknown. While land clearing for agriculture has continued, especially in the Mississippi Alluvial Plain, the rate of clearing has slowed. Furthermore, the trend to clear hardwood forests for agriculture may have been offset or even reversed since the last forest survey due to land being replanted to hardwoods, primarily under the Conservation Reserve Program and the Wetlands Reserve Program (Stanturf and others 1998). The vast acreage dominated by hardwood species, combined with the value of quality hardwood for both timber and wildlife habitat, attests to the tremendous opportunity for hardwood management in Louisiana, especially when one considers that hardwood lumber production accounted for only 1.91 million bf of the 1.148 billion bf harvested in Louisiana in 1999 (based on severance tax collections; Louisiana Office of Forestry web site - http://www.ldaf.state.la.us/forestry/index.htm).

Hardwood management in the southern United States has focused either on bottomland sites, especially first bottoms (Putnam and others 1960, Walker and Watterston 1972, Kellison and others 1981), or upland sites, especially in mountainous regions (Walker 1972, Smith and Eye 1986, Smith and others 1988). Less is known about hardwood growth and development on terrace sites. Terrace sites, often called second or even third bottoms, were former floodplains before the stream system moved to a lower elevation. These sites seldom flood, becoming inundated only in extremely high flood events. Therefore, terrace soils are usually well developed including argillic and fragipan horizons. Hodges (1997) stated that terrace sites can support hardwoods, but their growth and quality are generally not as good as active floodplain sites due to leaching of nutrients (and lack of nutrient recharge from flood events), development of pan horizons which restrict root development, and less favorable soil moisture relationships. Oftentimes terrace sites are bedded then converted to pine plantations. With the need for more information on hardwood management, particularly on terrace sites, a study was implemented to determine the growth and development of hardwood species on a terrace site using three different management objectives. Sixth-year results are reported.

MATERIALS AND METHODS

Study Site

The study site is located along Sandy Creek at the Idlewild Research Center, East Feliciana Parish, near Clinton, LA. Early 1940s photographs indicated the site was of old-field origin with scattered pine trees (Clifton 1987). The site also burned sometime prior to 1959 which resulted in a large number of multiple-stemmed hardwood trees due to resprouting.

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Table 1—Initial characteristics of major species in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana. Importance values are the sum of relative density and relative dominance (basal area)

Species	Trees per acre	Basal area (ft^2) per acre	Relative Density	Relative Dominance	Importance Value
sweetgum	19.54	5.27	12.80	6.48	19.28
loblolly pine	11.30	17.59	7.40	21.61	29.01
white oak	16.62	5.79	10.89	7.11	17.99
water oak	43.39	19.73	28.42	24.24	52.65
cherrybark oak	13.76	7.38	9.01	9.07	18.08
willow oak	34.02	20.17	22.28	24.78	47.07
other species[1]	14.06	5.47	9.20	6.71	15.92
Totals	152.69	81.40	100.00	100.00	200.00

[1] Other species include red maple, American hornbeam, pignut hickory, flowering dogwood, green ash, yellow-poplar, southern magnolia, crab apple, blackgum, sourwood, shortleaf pine, spruce pine, black cherry, southern red oak, swamp laurel oak, swamp chestnut oak, post oak, sassafras, horsesugar, winged elm, and American elm.

Four soil series were present on the study site (in order of magnitude): Calhoun silt loam, 65 percent (Typic Glossaqualf); Providence silt loam, 25 percent (Typic Fragiudalf); Bude silt loam, 5 percent (Glossaquic Fragiudalf); and Cascilla silt loam, 5 percent (Fluventic Dystrochrept). The first 3 soils were formed in loess or in a silty mantle, contained argillic horizons (2 had fragipan horizons), and were considered somewhat poorly drained to moderately well drained. The Cascilla silt loam was formed in silty alluvium, contained no pans, and was well drained.

Site index, base age 50 years, was estimated to be about 90 feet for cherrybark oak (*Quercus pagoda* Raf.), water oak (*Q*. *nigra* L.), and willow oak (*Q*. *phellos* L.) across the site, 115 feet for loblolly pine (*Pinus taeda* L.) on the Calhoun silt loam and 107 feet on the Providence silt loam. Average age for the oaks at the time of study installation was about 36 years with the scattered pine representing a second, older age class (Clifton 1987).

Study Design

In the Fall 1985, fourteen 2.541-acre (1-hectare) square plots were established in the stand. Each plot was surrounded by a 50-foot buffer strip. Species composition at the time of establishment was primary oak [importance value (sum of relative density and relative dominance) of 144; water, willow, white (*Q*. *alba* L.), cherrybark, swamp laurel (*Q*. *laurifolia* Michx.), swamp chestnut (*Q*. *michauxii* Nutt.), post (*Q*. *stellata* Wang.), and southern red (*Q*. *falcata* Michx.); table 1]. Other important species included sweetgum (importance value 19; *Liquidambar styraciflua* L.), and pines (importance value 31; shortleaf (*P*. *echinata* Mill.) and spruce (*P*. *glabra* Walt.) and loblolly).

Three treatments with 4 replications and a control with 2 replications were randomly assigned to these plots using a randomized incomplete block design (RIBD). These treatments are described below.

Timber—The timber treatment objective was to improve tree growth for timber production (veneer and sawlogs) by using a combination of crown thinning and improvement cutting to provide growing space for desirable trees (primarily red oaks). Trees marked for harvest were less-desirable species, suppressed, diseased, damaged, or otherwise poor candidates to remain until the next stand entry.

Wildlife Habitat—The wildlife habitat treatment objective was to improve wildlife habitat through a combination of crown thinning and improvement cutting to favor those tree species known to benefit wildlife populations regardless of tree quality relative to timber production. Mast-producing trees and cull and den trees were favored during marking. Also, one small opening, about 0.25 acre, was created in the plot center by severing all remaining trees $\leq$ 4 inches d.b.h. following harvesting of the overstory trees.

Timber/Wildlife Habitat—The third treatment involved combining the objectives of the first two treatments through a combination of crown thinning and improvement cutting for quality timber production and wildlife habitat. No small openings were made specific for the wildlife habitat objective aspect as in the wildlife habitat treatment.

All marking was done by developing tree class criteria (preferred stock, reserved stock, bolt stock, cutting stock, and culls; Putnam and others 1960, Dicke and others 1989) specific to each objective. Marking for the timber objective was conducted by a professional forester while marking for the wildlife habitat treatment was conducted by a professional wildlife biologist. These 2 individuals worked together to mark the combined timber/wildlife habitat treatment. Harvesting was conducted during late March to early June 1986 with a follow-up felling of all remaining marked trees.

Pre-harvest tree measurements were conducted during the Winter 1985/1986 and included species identification, d.b.h., crown class (Smith 1986), and tree class. Afterwards, all trees $\geq$ 4 inches were tagged at d.b.h. for future reference. Annual d.b.h. measurements were taken during the dormant season for the next 6 years. Trees that died each year were noted along with trees that grew into the 4-inch d.b.h. class ($\geq$ 3.6 inches).

Analyses involved using analysis-of-variance (ANOVA) in the RIBD. An alpha level of 0.10 was used to determine significance and Duncan's Multiple Range test was used to

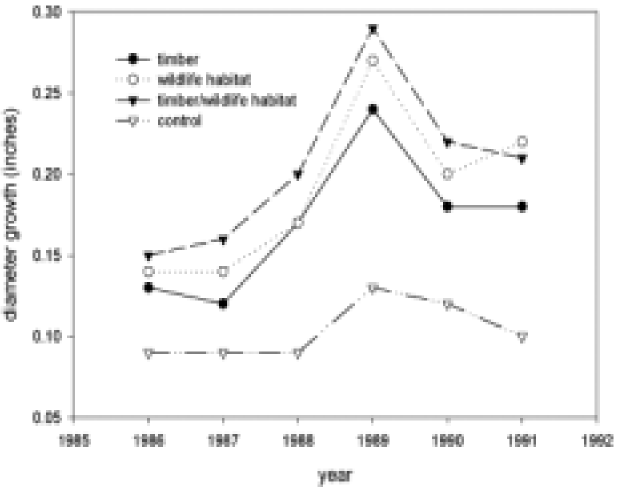

Figure 1—Annual diameter growth (inches) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

detect differences between treatments if the initial ANVOA was significant. Dependent variables tested included annual diameter and basal area growth, 6th-year diameter and basal area increment (referred to as cumulative growth), and stocking using Goelz (1995) stocking charts for bottomland hardwoods. These variables were tested for all trees combined, by crown class, and by 3 species groups (red oaks, white oaks, and pines). All measurements were taken in metric units then converted to English units for analyses and presentation. Scientific names follow Duncan and Duncan (1988).

Table 2—Cumulative diameter and basal area growth and changes in stocking over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

Treatment	Diameter inches	Basal Area sq. ft./acre	Stocking percent
Timber	1.04a[1]	17.54	7.6a
Wildlife Habitat	1.16a	16.53	6.5a
Timber/Wildlife Habitat	1.25a	17.30	8.5a
Control	0.65b	15.22	-0.1b
p-values	.0128	.7139	.0367

[1] Means followed by different letters within a column are significantly different at p=0.10.

RESULTS AND DISCUSSION

Diameter Growth

Diameter growth averaged about 0.10-0.25 inches per year across the study site. In general, tree diameter growth in any given growing season was greater for the treated plots compared to the controls (figure 1). Exceptions included 1986 when only the timber/wildlife habitat treatment was greater than the controls, and 1987 and 1990 when both the wildlife habitat and timber/wildlife habitat treatments were greater than the controls. A general trend of increasing diameter growth occurred each year during the first 4 years following study installation (figure 1). This increasing response may reflect increasing crown area in the residual trees and thus increased photosynthate production and/or better climatic conditions.

Table 3—Cumulative diameter growth by crown class over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana

Treatment	Crown Class dominant	codominant	intermediate	suppressed
timber	1.89a[1]	1.25a	0.72ab	0.53ab
wildlife habitat	1.71a	1.40a	0.76ab	0.82a
timber/wildlife habitat	1.81a	1.41a	0.93a	0.86a
control	1.36b	0.99b	0.47b	0.27b
p-values	.0373	.0305	0.586	.0237

[1] Means followed by different letters within a column are significantly different at p=0.10.

Table 4—Cumulative diameter growth (inches) by species group (see text for individual species within each species group) over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana

	Species Group		
Treatment	red oaks	white oaks	pines
Timber	1.18a[1]	0.76ab	1.87a
Wildlife Habitat	1.23a	0.89ab	1.98a
Timber/Wildlife Habitat	1.34a	1.02a	1.91a
Control	0.82b	0.43b	1.41b
p-values	.0069	.1780	.1836

[1] Means followed by different letters within a column are significantly different at p=0.10.

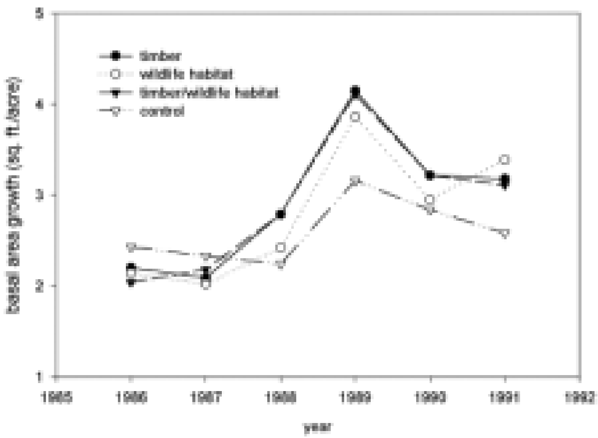

Figure 2—Annual basal area growth (square feet/acre) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

Cumulative diameter growth for all trees after 6 growing seasons was about 1-1.25 inches for the harvested treatments compared to only 0.65 inches for the controls (table 2). The cumulative diameter growth for the treated plots correspond to 1.75-2 inches of diameter growth over a 10-year period which is well below the 4-6 inches per decade considered indicative of a highly productive bottomland hardwood site (Briscoe 1955).

Cumulative diameter growth by crown class showed that dominant trees had greater growth compared to the codominant, intermediate, and overtopped crown classes (table 3). This was not unexpected given that dominant trees have larger, more healthy crowns compared to trees in the other crown classes. Codominant trees had the second largest cumulative diameter growth while no difference in cumulative diameter growth occurred between the intermediate and overtopped classes. As with cumulative diameter growth for all trees by treatment, growth was greater within a crown class for the treated plots compared

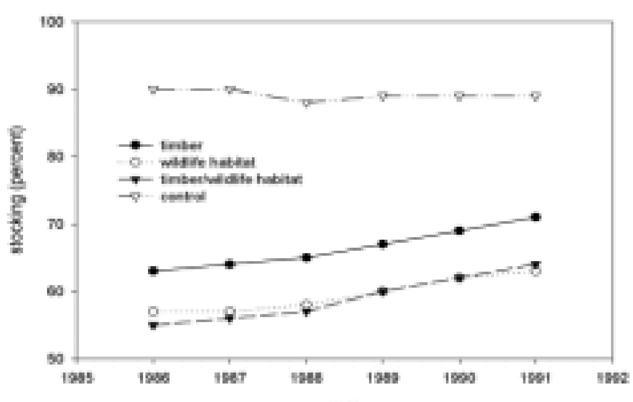

Figure 3—Changes in stocking (percent) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

to the controls. Among species groups, the pines had greater cumulative diameter growth compared to the red oak and white oak groups with red oaks having greater growth than white oaks (table 4).

Basal Area Growth

Basal area growth averaged 2.78 square feet per acre per year between the partial cutting treatments and controls. Few differences occurred in basal area growth between the treatment and controls; exceptions being in 1988 when the timber and timber/wildlife habitat treatments had greater growth compared to the controls and 1991 when all 3 partial cutting treatments had growth greater than the controls (figure 2). No differences were found in the 6-year cumulative basal area growth between the treatments and the controls (table 2). No differences were also found in cumulative basal area growth between treatments and controls within each of the 4 crown classes or the 3 species groups. While treated plots had greater diameter growth, the control plots had a greater number of trees per acre to match the increases in basal area growth in the treated plots.

Stocking

Stocking was evaluated using Goelz (1995) stocking equation for southern bottomland hardwoods. Goelz (1995) noted that this equation was developed from Putnam and others (1960) table for stocking of an even-aged bottomland hardwood forest and not on long-term replicated research. Furthermore, since the present study was conducted on a well-developed terrace, and not on an active floodplain (Hodges 1997), applicability of Goelz's (1995) stocking equation to this type of site may be questionable.

Initial stocking in the control plots average 89 percent. Stocking for the treated plots was less because only post-harvest d.b.h. measurements, but pre-1986 growing season, were conducted (figure 3). Stocking remained about 89 percent for the control plots throughout the 6-year study period (figure 3). Changes in stocking for the treated plots showed a fairly consistent pattern with stocking in the timber objective treatment always being greater than in the wildlife habitat and timber/wildlife habitat treatments. This difference was due to the greater initial stocking in the timber objective treatment. No difference occurred in the change in stocking over the 6-year study period for the partial cutting treatments, averaging about 1-1.5 percent increase per year (table 2).

CONCLUSIONS

Several conclusions can be made based on the results from partial cutting in hardwoods growing on a terrace site.

First, hardwoods growing on a terrace site such as the one found on the Idlewild Research Center will respond to partial cutting, especially red oak species. One can expect about 2 inches of diameter growth per decade, 3 square feet of basal area growth per year, and about a 1 percent increase in stocking per year.

Second, pines, especially loblolly pine, grew better than hardwoods on the terrace site in this study. Intensive culture of pines, such as bedding and use of genetically-improved seedlings, would result in even better growth.

Third, few differences were found between the timber, wildlife habitat, and timber/wildlife habitat treatments, at least in terms of diameter and basal area growth. Assessments of log quality, financial returns, and specific wildlife habitat measures, such as mast production, quantity and quality of browse material, and vertical and horizontal structure, must be made before more definite comparisons can be made regarding treatment effects. The important point is to have specific management objectives stated before commencing silvicultural operations.

Finally, when determining management objectives, especially regarding decisions to convert terrace hardwoods to pines, keep in mind that hardwoods will grow on such sites, making mixed pine-hardwood management options viable. Furthermore, in afforesting pastures on terrace sites, planting pine and allowing hardwoods to develop underneath the pine following natural successional tendencies may constitute a viable “hardwood rehabilitation” option.

REFERENCES

Briscoe, C.B. 1955. Diameter growth of selected bottomland hardwoods as affected by species and site. LSU Forestry Notes #5, Baton Rouge, LA: Louisiana State University, 2 p.

Clifton, J.R. 1987. First-year tree growth and stand characteristics after an initial thinning-improvement cutting in a pole-sized natural hardwood stand. Baton Rouge, LA: Louisiana State University. 86 p. Masters thesis.

Dicke, S.G.; Linnartz, N.E.; Clifton, J.R. 1989. Early response of a mixed oak-gum-pine stand to improvement cuttings. In: Miller, J.H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rpt. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Experiment Station: 303-307.

Duncan, W. H.; Duncan, M.B. 1988. Trees of the southeastern United States. Athens, GA: The University of Georgia Press. 322 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19: 103-104.

Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management. 90: 117-125.

Kellison, R.C.; Federick, D.J.; Gardner, W.E. 1981. A guide for regenerating and managing natural stands of southern hardwoods. Raleigh, NC: North Carolina Agricultural Research Service. 24 p.

Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

Smith, D.M. 1986. The practice of silviculture, 8th edition. John Wiley. 527 p.

Smith, H.C.; Eye, M.C. (eds.). 1986. Proceedings: guidelines for managing immature Appalachian hardwood stands. 1986 May 28-30, Morgantown, WV, Publication 86-02. Bethesda, MD: Society of American Foresters. 283 p.

Smith, H.C.; Perkey, A.W.; Kidd, W.E.,Jr. (eds.). 1988. Proceedings: guidelines for regenerating Appalachian hardwood stands. 1988 May 24-26, Morgantown, WV, Publication 88-03. Bethesda, MD: Society of American Foresters. 293 p.

Stanturf,J.A.; Schweitzer,C.J.; Gardiner,E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica. 32: 281-297.

Vissage, J.S.;Miller, P.E.; Hartsell, A.J. 1992. Forest statistics for Louisiana Parishes - 1991. Res. Bull. SO-168. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 65 p.

Walker, L.C. 1972. Silviculture of southern upland hardwoods. Bulletin 22. Nacogdoches, TX: Stephen F. Austin State University. 137 p.

Walker, L.C.; Watterson, K.G. 1972. Silviculture of southern bottomland hardwoods. Bulletin 25. Nacogdoches, TX: Stephen F. Austin State University. 78 p.

AMERICAN CHESTNUT, RHODODENDRON, AND THE FUTURE OF APPALACHIAN COVE FORESTS

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Abstract—By the mid 1930s, the southern Appalachians had been heavily cutover and the dominant hardwood, American chestnut (Castanea dentata), had succumbed to the chestnut blight (Cryphonectria parasitica). Forests that had been burned on a frequent basis for millennia were now protected and fire was excluded in large degree. We estimated the pre-blight importance of chestnut in cove forests and the recovery of the overstory canopy on these rich sites following the blight and logging early in the last century. The overstory has largely recovered from the blight, although chestnut is not longer a functional component of the cove forest ecosystem. Following the blight, the successional pathway on two unlogged, old-growth sites proceeded to an oak association; on two logged sites, succession proceeded to mesophytic forests. A gradual change in the understory has occurred in many coves that threatens their future diversity and productivity. Encroaching rhododendron (Rhododendron maximum) thickets are severely inhibiting hardwood regeneration and reducing herbaceous/shrub species richness. Neither shade-tolerant nor shade-intolerant hardwood species are becoming established in canopy-gaps where rhododendron is present in moderate to high densities. Rhododendron has become an ecologically dominant species because it thrives on disturbance and, once established, inhibits other species. New management techniques will have to be developed if diversity and productivity of cove hardwood forests are to be sustained.

INTRODUCTION

Throughout the past century, hardwood forests of the southern Appalachians have undergone major changes as they recovered from heavy logging, loss of American chestnut to a blight, and exclusion of frequent fires. Nearly all of the southern Appalachian Mountains were heavily cutover between 1880 and 1930. The chestnut blight (*Cryphonectria parasitica*), introduced in the Northeast in the early 1900s and regarded as the most devastating ecological event ever recorded in the southern Appalachians, essentially removed that species as a canopy dominant by the late 1930s. Recovery of the forest overstory following the blight is well documented (Keever1953, Nelson 1955, Woods and Shanks 1959, Runkle 1982); however, effects of chestnut's demise on shrub and herb synusia have rarely been described.

Another major disturbance that shaped the current composition and structure of the region's forests was the exclusion of frequent fire as an ecological process. Exclusion of fire is regarded as a disturbance because it is a deviation from the normal burning regime that existed in the southern Appalachians for millennia. Burning by native Americans would have created a mosaic of vegetative conditions but the general appearance would have been a more open forest with a greater abundance of herbaceous vegetation (Van Lear and Waldrop 1987, Barden 1997, Delcourt and Delcourt 1997). Exclusion of fire allowed rhododendron (*Rhododendron maximum*), an ericaceous woody shrub, to extend its influence far beyond the streamsides where it occurred at the turn of the past century (Ayres and Ashe 1902, Monk and others 1985).

Expansion of rhododendron is a concern for hardwood forest managers because recruitment of canopy tree seedlings is inhibited under the dense cover of rhododendron (Hedman and Van Lear 1994, Clinton and others 1994, Clinton and Vose 1996, Baker and Van Lear 1998). It is debatable whether hardwood seedlings, once established, can grow through rhododendron thickets and become overstory trees, thereby sustaining the diversity and productivity of cove forests. The density and size of rhododendron thickets determines whether hardwood seedlings can successfully become established.

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This paper summarizes results of several separate, but related, studies conducted over the past decade in cove/riparian forests of the southern Appalachians. Our objectives were to: 1) quantify the importance of pre-blight chestnut in these forests, 2) describe forest recovery following logging and the chestnut blight, with special emphasis on the understory and regeneration layers, 3) identify relationships between density of rhododendron thickets and species richness/ regeneration, and 4) examine effects of rhododendron on canopy-gap dynamics and establishment of forest regeneration. All studies were conducted on the lower slopes of coves, i.e., riparian forests, within 35 meters of a stream. From this point, we will call these cove forests.

METHODS

Study Areas

All studies were conducted in the Blue Ridge physiographic province of the southern Appalachians. Study sites were located on the Sumter National Forests in South Carolina, the Chattahoochee National Forest in Georgia, and the Pisgah and Nantahala National Forests in North Carolina. Soils on these sites are classified as Typic Dystrochrepts, and are commonly 50-152 centimeters deep. This area experiences a temperate humid climate with a growing season of approximately 180 days. Most of the ample precipitation occurs in the growing season.

Methods for each of the studies are summarized below. Refer to published papers by the authors for greater detail on methods. In this paper, rhododendron refers to *Rhododendron maximum*, which was by far the most dominant ericaceous shrub on study sites.

Chestnut's Importance in Cove Forests

Four forest sites containing chestnut were selected along first- or second-order streams (elevations 363 to 780 meters). Two of the sites, Thomas Creek and Tallulah River, showed signs of chestnut salvage logging and general logging in the past, while the other two sites, Slatten Branch and Little Santeetlah Creek, were remnant old-growth stands with no evidence of ever having been logged. All identifiable chestnut snags were measured for ground-line diameter (GLD) and diameter breast height (DBH), where possible, along stream reaches ranging in length from 363-780 meters. A total linear distance of 3.1 kilometers was surveyed on the four sites, representing 16.4 hectares of southern Appalachian cove forests (Vandermast and Van Lear 2001).

We identified 589 chestnut snags and stumps in the riparian forests of the four study sites, 207 of which were intact enough to obtain accurate DBH data. Using the derived linear relationship between DBH and ground-line diameter (R^2 = 0.947), we estimated DBH of the remaining chestnuts whose ground-line diameter only could be estimated.

Forest Recovery Following the Blight and Logging

Composition of the current cove forest at the four sites was determined by sampling 7x 7 meter plots centered around 58 randomly selected chestnut stumps or snags (10 percent of the 589 identified). Herbaceous vegetation was sampled within five 1 square-meter quadrats in each plot. Trees and seedlings were tallied by species on 0.04 hectare plots and saplings on 0.025 hectare plots using the Braun-Blaunquet cover class method. Rhododendron stems were counted in each 0.04 hectare plot.

Species richness was calculated and compared among sites and between old-growth and logged sites. Frequency values, i.e., the proportion of plots containing a species, were used to compare old-growth to logged forests and to compare plots with high and low rhododendron importance values. Regeneration of overstory hardwood species was regressed against rhododendron coverage (Vandermast and Van Lear 2001).

Relationships Between Rhododendron Coverage and Species Richness

Fifty-five 10x20 meter plots were randomly located along Wine Spring Creek in the Nantahala National Forest. All stems > l centimeter basal diameter were recorded by species in each plot. Average dbh, density, basal area, and importance value (relative density + relative basal area/2) were calculated for each species by canopy strata. Diameter of each rhododendron stem was measured and placed into I centimeter diameter classes. Biomass of rhododendron foliage and stems was estimated from allometric equations developed from 41 randomly chosen stems ranging from 1 to 4 centimeters basal diameter.

The regeneration layer (woody and herbaceous stems < 1 centimeter basal diameter) was inventoried on five transects, each 10 meter long, across the width of each plot. Frequency and percent cover of each species that intersected the transect were recorded by 1 meter intervals and importance values (relative frequency + relative coverage/2) were calculated. Discriminant analysis, using basal area and stem density, was used to quantitatively classify the 55 sample plots into four discrete rhododendron thicket-density categories (Baker and Van Lear 1998).

Effects of Rhododendron on Canopy-Gap

Dynamics

Twenty-two canopy gaps (elevations from 518 to 758 meters) resulting from wind-throws were selected in southern Appalachian cove forests. Eleven of the canopy gaps contained understories of rhododendron with a minimum density of 2000 stems/hectare and eleven other gaps contained no rhododendron. Selected gaps had to meet certain criteria, including 1) being less than 7 years old, 2) occupying only mesic site types, and 3) being within 35 meters of a stream. Gap size ranged from one-tree openings to larger gaps resulting from the death of up to six trees (Rivers and others 2000).

Vegetation was sampled along two gradients: 1) longest distance across the gap, and 2) a shorter distance perpendicular to the first. The two gradient lines intersected at the center of the gap. Advanced regeneration and new seedlings were inventoried in 1 meter wide transects located along each of the two principle gradient lines. Transects

Table 1—Mean diameter (DBH) and basal area (BA) for chestnuts and live trees on four southern Appalachian cove forest sites

Site	Chestnut		Live Trees	
	DBH (cm)	BA/ha (m^2)	DBH (cm)	BA/ha (m^2)
Old-growth				
Slatten Branch	56.2a[a]	8.9a	26.2a	22.7a
Little Santeetlah	73.7c	12.3c	28.6a	37.5a
Logged				
Thomas Creek	43.9b	8.4b	26.9a	28.8a
Tallulah River	53.6a	10.0a	27.6a	32.9a

[a] Means followed by the same letter within a column are not significantly different at the 0.01 level.

were divided into 1 meter sections to distinguish vegetative preference from the center of the gap towards the surrounding undisturbed forest. Percent cover of rhododendron was estimated and placed into Braun-Blaunquet category classes for each 1 square-meter section and averaged to determine total percent cover for each gap. The area of a gap was determined using the formula for an ellipse.

All stems < 10 centimeter ground-line-diameter were considered understory and all stems > 10 centimeter gld were considered either midstory or overstory. Stems < l centimeter were considered part of the regeneration layer. Importance Values were calculated as described above.

Statistical Analyses

Chestnut and current live stem diameters and basal areas were compared among logged and old-growth sites using PROC GLM and Analysis of Variance in SAS (SAS Institute,

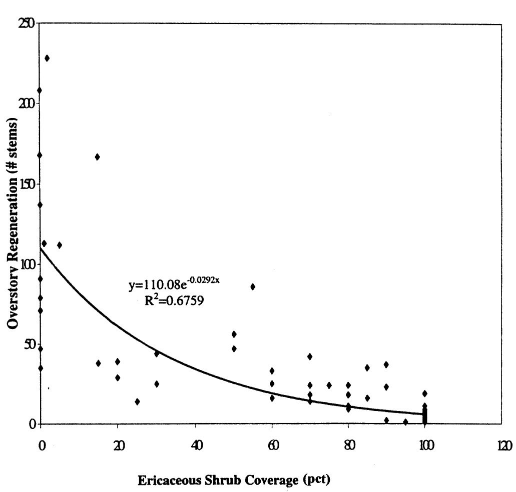

Figure 1—Effects of increasing ericaceous shrub coverage (predominantly *Rhododendron maximum*) on a number of regeneration stems (seedlings and saplings) of overstory tree species on 0.04 hectacre plots

Inc. 1987). Tukey's Least Significant Difference Test and orthogonal contrasts were used to make specific tests. Regression analysis was used to develop a model predicting chestnut DBH from ground-line diameters. Forest recovery plots were clustered based on similar vegetative composition using Detrended Correspondence Analysis (DECORANA) and Two-way Indicator Species Analysis (TWINSPAN) (Hill 1970). Discriminant analysis was used to categorize Wine Spring Creek plots into different levels of rhododendron-thicket densities using PROC DISCRIM (SAS Institute, Inc. 1987). Differences in regeneration layer richness and cover among rhododendron density categories were tested with PROC GLM. Non-linear regression was used to quantify relationships between species richness and rhododendron coverage in canopy gaps.

RESULTS

Chestnut's Importance in Riparian Forests

Chestnut was an important component of southern Appalachian cove forests (table 1). Average DBH of standing chestnut snags was about 2 - 2.5 times larger than that of live trees currently growing on old-growth and logged sites (Vandermast and Van Lear 2001). Chestnut basal area ranged from 8.9 to 12.3 square meters per hectare, suggesting that the species represented between 25 to 40 percent of the pre-blight lower cove forest if current conditions are similar. Old-growth sites tended to have larger diameter trees than logged sites, although only chestnuts on Little Santeetlah Creek were significantly larger.

Following the Blight and Logging

On unlogged, old-growth sites, current overstory composition indicates forest succession following the chestnut blight produced an oak association with a component of mesophytic species such as Eastern hemlock (*Tsuga canadensis*) and black birch (*Betula lenta*) (Vandermast and Van Lear 2001). On logged sites, current overstory composition is dominated by cove mesophytic species, such as yellow-poplar (*Liriodendron tulipifera*), black birch, red maple (*Acer rubrum*), and Eastern hemlock. Seedling-sized sprouts of American chestnut are still common in these riparian forests, although no sapling-sized sprouts were tallied. Chestnut sprouts were absent in rhododendron thickets, which were significantly denser in logged forests. Overstory regeneration (seedlings and saplings) was negatively impacted by rhododendron (figure 1), decreasing exponentially as rhododendron coverage increased. The only species capable of successfully regenerating in dense rhododendron thickets was Eastern hemlock, and even this shade-tolerant conifer had low stem densities when rhododendron density was high. Rhododendron was ubiquitous on both the logged and old-growth sites, occurring on 81 to 90 percent of the 58 plots. The two logged sites had significantly denser rhododendron thickets ($p = 0.0094$) than the two-old growth sites.

Relations Between Rhododendron Coverage and Species Richness

Density and biomass of rhododendron were characterized in the understory of a second-growth riparian forest dominated by yellow birch (*Betula alleghaniensis*) and black birch (age about 42 - 44 years old) (Baker and Van Lear 1998).

Table 2—Range of rhododendron stem density and biomass in each thicket density category

Rhododendron thicket density	Stem density (thousands/hectare)	Above-ground biomass (tons/hectare)
High	8.0 - 17.4	18.1 - 34.0
Medium	5.1 - 10.5	8.7 - 18.3
Low	2.8 - 6.5	2.9 - 8.4
Scarce	0.0 - 2.6	0.0 - 3.0

Table 3—Effects of rhododendron density on species richness in the regeneration layer during Fall and Spring sampling periods

Rhododendron thicket density	Richness (# species)	
	Fall	Spring
High	6a[a]	7a
Medium	9ab	12b
Low	18c	22c
Scarce	26d	29d

[a] Means followed by the same letter within a column are not significantly different at the 0.01 level.

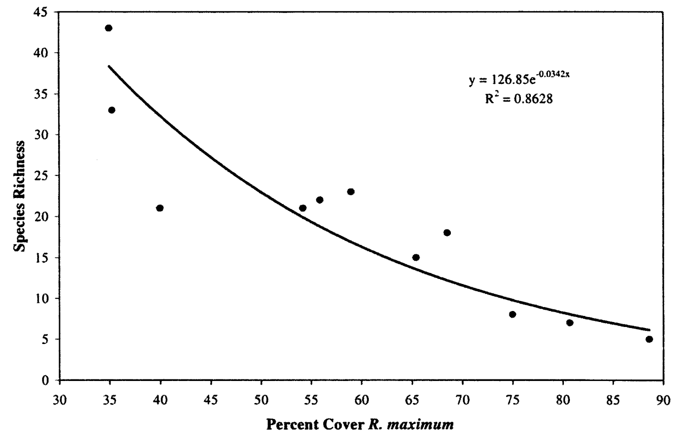

Figure 2—Relation between species richness and percent cover of rhododendron in southern Appalachian forest gaps

Rhododendron densities exceeded 17,000 stems per hectare in high coverage plots and biomass reached 34 tons per hectare (table 2). Basal area of rhododendron thickets averaged 11 - 22 square meters per hectare where thicket density was high.

Total species richness in the regeneration layer and percent rhododendron cover were inversely related (R^2 = 0.92) (Baker and Van Lear 1998). On average, 6-7 plant species were found on plots with high densities of rhododendron whereas 26-29 species were found where rhododendron was scarce or absent (table 3). Cover of species other than rhododendron ranged from 5 percent where rhododendron density was high to 43-62 percent where its density was classified as scarce. Similar relationships were found by Hedman and Van Lear (1994) and Vandermast and Van Lear (2001).

Based on aging of stems through ring counts, rhododendron apparently began to dominate the understory of this birch-dominated forest on Wine Spring Creek within 15-20 years after logging (Baker and Van Lear 1998). It has increased in density and coverage and is now so dominant in terms of number of stems, basal area and biomass that it appears doubtful that valuable hardwood species such as yellow-poplar, yellow and black birch, black cherry (*Prunus serotina*), sugar maple, basswood (*Tilia americana*), yellow buckeye (*Aesculus octandra*), Fraser magnolia (*Magnolia fraseri*), and others will be able to establish themselves. In the regeneration layer of rhododendron thickets on the Wine Spring Creek site, Eastern hemlock, red maple, American beech (*Fagus grandifolia*), yellow birch, and Northern red oak (*Quercus rubra*) were present in small numbers. However, rhododendron so dominated the regeneration and understory layers that it appeared unlikely that many of these will reach midstory and overstory strata.

Effects of Rhododendron on Canopy-Gap Dynamics

Average canopy gap size in this study was 157 square meters (range 41 to 286 square meters). Species richness decreased exponentially as rhododendron coverage increased in canopy gaps (figure 2). Average midstory density, an indicator of whether woody species are becoming established in the stand, was 10 fold less in gaps containing rhododendron. Where rhododendron was present prior to gap formation, there was little advanced regeneration and, if present, it was not developing into the midstory. Herbaceous density was even more adversely affected by the presence of rhododendron in gap understories.

As density of the rhododendron understory increased under canopy gaps, shade- intolerant species such as yellow-poplar were eliminated and shade-tolerant species such as sugar maple were severely reduced to levels where little or no recruitment into the overstory occurred (Rivers and others 2000). Eastern hemlock, an extremely shade-tolerant conifer, was the only species capable of regenerating in canopy gaps where moderately dense rhododendron thickets occurred, and even here hemlock tended to regenerate in small patches where rhododendron coverage was lower. Maximum above-ground biomass of rhododendron measured in this study was 37 tons per hectare, similar to that estimated in an earlier study by Baker and Van Lear (1998).

Average tree seedling height was greater in gaps without rhododendron than in those with it, except for intolerant species near the gap edge where shading from the adjacent overstory reduced growth. Seedling height of intolerant species like yellow-poplar and sweet birch significantly decreased as distance from the center of the gap increased, whereas height of shade-tolerant species like red maple and Eastern hemlock varied little along gap gradients.

DISCUSSION

Due to its sensitivity to frost, glaze, and ice (Parker et al. 1993), American chestnut has been thought to be unsuited for ravines and valleys. Chestnut was most often listed as a dominant species on ridges (Abrams and Ruffner 1995, Abrams and McCay 1996) and mid-slope areas (Whitaker 1956). While recognized as a member of cove forests (Ayers and Ashe 1902, Woods and Shanks 1959, Lorimer 1980, McCarthy and Bailey 1996), chestnut had never been quantitatively described in cove forests.

American chestnut was clearly a dominant tree in southern Appalachian cove forests. The species had a larger average diameter and made a greater contribution to basal area than any species of the current live tree association. Results of the studies reported here support data from Hedman et al. (1996), who quantified the importance of chestnut as a major contributor of large woody debris to southern Appalachian streams. If chestnut comprises a large portion of a stream's large woody debris, the species must have been an important component of lower slopes in cove forests.

The demise of the chestnut has been implicated in the spread of rhododendron thickets (Woods and Shanks 1959, Clinton et al. 1994, Clinton and Vose 1996). Our results support this contention and also indicate that logging disturbance encourages the spread of rhododendron even more, as suggested by McGee and Smith (1967). Following the blight, the two unlogged, old-growth sites succeeded to an oak association dominated by white oak (*Quercus alba*), chestnut oak (*Q. prinus*), and Northern red oak, with a strong component of black birch and Eastern hemlock. The dominance of oak species on the two old-growth sites suggests that periodic fire had occurred in these stands prior to the blight, which allowed oaks to dominate the advance regeneration (Brose and Van Lear 1998, Brose and others 1999) and control rhododendron (Van Lear and Waldrop 1989, Van Lear 2000).

Logged sites succeeded toward a mixed mesophytic forest type dominated by yellow-poplar, Eastern hemlock, red maple, and black birch, with a small component of oaks and hickory. Logging disturbance, which provides a mineral soil seedbed and greater insolation, would be expected to favor pioneer species like yellow-poplar and black birch. Large canopy gaps (0.04 hectare and larger) are thought necessary for abundant regeneration of yellow-poplar (Busing 1993, 1995). Apparently, the deaths of individual chestnut trees in the two old-growth areas did not create gaps large enough for abundant yellow-poplar regeneration.

Rhododendron has replaced American chestnut as the ecological dominant in many cove forests of the southern Appalachians (Vandermast and Van Lear 2001). Following the chestnut blight, logging, and fire exclusion early in the last century, rhododendron has expanded far upslope and now tends to direct forest succession and development by affecting establishment and growth of advance regeneration and seedlings. With the exception of Eastern hemlock, no other woody species appeared to have the ability to attain overstory status on these study sites, although Phillips and Murdy (1985) and Clinton and Vose (1998) noted that red maple could regenerate and become established on some sites dominated by rhododendron. Herbaceous species richness declined markedly with increases in density of rhododendron thickets and after decades of rhododendron dominance may now be lost from certain sites in these riparian/cove forests.

The diversity of cove forests of the southern Appalachians is thought to be maintained through gap-phase disturbances (Barden 1981, Runkle 1982, Busing 1993). However, canopy gaps with medium density rhododendron thickets in the understory had no hardwood species in the midstory strata. Only Eastern hemlock was present in the midstory, indicating that most hardwood species will fail to become members of the overstory canopy.

Succession in rhododendron thickets appears to fit the Inhibition Pathway model proposed bv Connel and Slatyer (1977). In this model, certain plant species modify their environment so that recruitment of both early and late successional species is inhibited as long as current vegetation remains intact. Rhododendron dominates the regeneration layer and prevents successful recruitment of other species into other canopy strata because of its dense shade, acidic litter (Boettcher and Kalisz 1990) and possible allelopathic effects (Rice 1979, Nielsen et al. 1999). Without major disturbance, rhododendron will apparently occupy these sites indefinitely.

CONCLUSIONS

As overstories of southern Appalachian forests recovered from heavy logging, chestnut blight, and fire exclusion of the past century, rhododendron became the dominant understory component in many cove forests of the region. Rhododendron now poses a major threat to the sustained diversity and productivity of many cove forests. Recent research provides convincing evidence that expansion of rhododendron thickets has a detrimental effect on regeneration of high quality hardwood species, as well as adverse effects on the richness of the herbaceous layer. Canopy gaps created by various types of disturbances are not regenerating to hardwoods but are becoming denser and taller thickets of rhododendron. On some sites, successional trends indicate that thickets of this dense ericaceous shrub will become the climax vegetation.

Forest managers must find new methods to manage the hardwood resource in this region. A hands-off approach until final harvest will not regenerate diverse and productive hardwood forests on cove sites where rhododendron has become estabished. Ways to control the spread and reduce the biomass of rhododendron tickets must be found. Greater efforts are needed to understand community dynamics in Southern Appalachian cove forests and to learn how to direct successional patterns.

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REFERENCES

Abrams, M.D.; D.M. McCay. 1996. Vegetation-site relationships of witness trees (1780-1856) in the pre-settlement forests of eastern West Virginia. Canadian Journal of Forest Research. 26: 217-224.

Abrams, M.D.; C.M. Ruffner. 1995. Physiographic analysis of witness-tree distribution (1765-1789) and present forest cover through north central Pennsylvania. Canadian Journal of Forest Research. 25: 659-668.

Ayres, H.B.; W.W. Ashe. 1902. Description of the southern Appalachian forests, by river basins. Message from the President of the United States transmitting report of the Secretary of Agriculture in relation to the forests, rivers and mountains of the southern Appalachians. Appendix A. 192 p.

Baker, T.T.; D.H. Van Lear. 1998. Relations between density of rhododendron thickets and diversity of riparian forests. Forest Ecology and Management 109: 21-32.

Barden, L.S. 1981. Forest development in canopy gaps of a diverse hardwood forest of the southern Appalachian Mountains. Oikos 37: 205-209.

Barden, L.S. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. Natural Areas Journal. 17: 149-152.

Boettcher, S.E.; P.J. Kalisz. 1990. Single-tree influence on soil properties in the mountains of eastern Kentucky. Ecology. 71: 1365-1372.

Brose, P.T.; D.H. Van Lear. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. Canadian Journal of Forest Research. 28: 331-339 p.

Brose, P.T.; D.H. Van Lear; P.D. Keyser. 1999. A shelterwood-burn technique for regenerating productive upland oak sites in the Piedmont region. Southern Journal of Applied Forestry. 23: 158-163.

Busing, R.T. 1993. Three decades of change at Albright Grove, Tennessee. Castanea. 58: 231-242.

Busing, R.T. 1995. Disturbance and the population dynamics of *Liriodendron tulipifera*: simulations with a spatial model of forest succession. Journal of Ecology. 83: 45-53.

Clinton, D.B.; L.R. Boring; W.T. Swank. 1994. Regeneration patterns in canopy gaps of mixed-oak forests of the Southern Appalachians: Influences of topographic positioned evergreen understory. American Midland Naturalist. l32: 308-319.

Clinton, B.D; J.M. Vose. 1996. Effects of *Rhododendron maximum* L. on *Acer rubrum* seedling establishment. Castanea. 61: 38-45.

Connell, J.H.; R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist. 111: 1119-1144.

Delcourt, H.R.; P.A. Delcourt. 1997. Pre-Columbian native American use of fire on Southern Appalachian landscapes. Conservation Biology. 11: 1010-1014.

Hedman, C.W.; D.H. Van Lear. 1994. Structure and composition of Southern Appalachian riparian forests. Bulletin Torrey Botanical Club. 122: 134-144.

Hedman, C.W.; D.H. Van Lear; and W.T. Swank. 1996. In-stream large woody debris loading and riparian forest seral stage associations in the southern Appalachian Mountains. Canadian Journal of Forest Research. 26: 1218-1227.

Hill, M.O. 1979. TWINSPAN: A FORTRAN program arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Cornell University Department of Ecology and Systematics.

Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34: 44-55.

Lorimer, C.G. 1980. Age structure and disturbance history of a southern Appalachian virgin forest. Ecology 61: 1169-1184.

McCarthy, B.C.; D.R. Bailey. 1996. Composition, structure and disturbance history ofCrabtree Woods: an old-growth forest of western Maryland. Bulletin of the Torrey Botanical Club. 123: 350-365.

McGee, C.E.; R.C. Smith. 1967. Undisturbed rhododendron thickets are not spreading. Journal of Forestry. 65: 334-336.

Monk, C.D.; D.T. McGinty; F.P. Day, Jr. 1985. The ecological importance of *Kalmia latifolia* and *Rhododendron maximum* in the deciduous forest of the southern Appalachians. Bulletin of the Torrey Botanical Club. 112: 187-193.

Neilsen, E.T., J.F. Walker, O.K. Miller, S.W. Semones, T.T. Lei, and B.D. Clinton. 1999.Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): Could allelopathybe a cause? American Journal of Botany. 86: 1597-1612.

Nelson, T.C. 1955. Chestnut replacement in the southern highlands. Ecology. 36: 352-353.

Parker, G.G., S.M. Hill, and L.A. Kuehnel. 1993. Decline of understory American chestnut (*Castanea dentata*) in a southern Appalachian forest. Canadian Journal of Forest Research. 23: 259-265.

Phillips, D.L. and W.H. Murdy. 1985. Effects of rhododendron (*Rhododendron maximum* L.) on regeneration in southern Appalachian hardwoods. Forest Science. 31: 226-233.

Rice, E.L. 1979. Allelopathy, an update. Botanical Review. 45: 15-109.

Rivers, C.T., D.H. Van Lear, B.D. Clinton, and T.A. Waldrop. 2000. Community composition in canopy gaps as influenced by presence or absence of *Rhododendron maximum*. In: Haywood, J.D., ed. Proceedings of the Tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 57-60.

Runkle, J.R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. Ecology 63: 1533-1546.

Runkle, J.R. 1985. Disturbance regimes in temperate forests. The Ecology of Natural Disturbance and Patch Dynamics. S.T.A. Pickett ;P.S. White, eds. New York: Academic Press: 17-33.

SAS Institute, Inc. 1987. SAS/STAT guide for personal computers, 6th ed. SAS Institute, Inc.,Gary, NC.

Vandermast, D.B.; D.H. Van Lear. (In press). Riparian forest recovery in the southern Appalachians following the chestnut blight. Forest Ecology and Management.

Van Lear, D.H.; T.A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. USDA Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-54. 20p.

Waldrop, T.A., ed. 1989. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type; 1989 April 18-19; Atlanta, GA. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 271p.

Whitaker, R.H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs. 26: l-80.

Woods, F.W.; R.E. Shanks. 1959. Natural replacement of chestnut by other species in the Great Smoky Mountains National Park. Ecology. 40: 349-361.